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Development of User Guidelines for Selected Retardant Aircraft

Honeywell

DEVELOPMENT OF USER GUIDELINES FOR SELECTED RETARDANT AIRCRAFT

Final Report

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SECTION I
INTRODUCTION

This report documents the generation of User Guidelines for selected airtankers under Contract 26-3332 with the Northern Forest Fire Laboratory, U. S. Forest Service. Specifically, it documents:

- The methodology by which the guidelines and their general instruction manual were generated.
- The results of subsidiary studies to improve on, simplify, and increase the capability of the computer simulations that make the generation of such guidelines possible.
- The computer program and its operations.

The guidelines themselves and a general instruction manual for their use are provided under separate cover. For reference purposes, the Instruction Manual and an example User Guide are also reproduced as Attachments 1 and 2 to this report.

User Guideline development is summarized in Section II. Succeeding sections detail the results of effort on specific tasks as called for in the contract.

- Task 1 – Modify the program to operate from the direct input of measured flow-rate data.
- Task 2 – Modify the program to predict pattern performance with water-like retardants.

- Task 3 – Improve program documentation.
- Task 4 – Generate User Guidelines.

Appendix A provides detailed instructions on operation of the computer simulation, and Appendix B gives the derivation of accuracy-limit curves used in the Best-Strategy charts in the User Guides.

SECTION II
GUIDELINE DEVELOPMENT SUMMARY

Work on the High-Altitude Drop Mechanization Study (Ref. 1-3) resulted in the development of a computer simulation capable of predicting retardant ground patterns over a range of aircraft velocities and altitudes. The program, based on original work by J. I. MacPherson, was substantially modified in the method of generating the downrange retardant distribution, and its crossrange expansion. This was made possible by the use of an analytical program (MIX 2/RETARD) that enabled the direct comparison of real patterns, generated in flight tests, with simulation results. By adjusting empirical constants within the program, rules were generated which enable the prediction to match actual patterns will remarkable accuracy. When the rules were then applied to other aircraft tanking systems, the program continued to provide good predictions.

Late in the High-Altitude Retardant Drop Mechanization Program, measured data on actual fluid-flow rates became available. These data suggested that the subroutine used to predict flow-rate from tank geometry was not entirely accurate. When actual flow-rates were substituted, however, the predictive capability of the simulation was strikingly improved. This discovery led to the proposition that the simulation using measured flow-rate data could be used operationally to identify best usage strategies for existing airtankers.

Employing the simulation, it is possible to run any aircraft for which measured flow-data are available through an extensive computer-generated test series, such as that conducted on the CL-215 by the Forest Service. Since each flight takes less than one second of computer time, a thorough examination of tanking capabilities can be conducted

in a few days, allowing for preparation of the input, validation of the runs, and repeats as necessary.

The problem remains to digest and summarize the potentially vast amount of data thus generated in terms useful to operational personnel. The latter was the primary concern of the User Guideline design task.

PREPARATORY PROGRAM CHANGES

The first task of the contract required the modification of the simulation to accept measured flow-rate directly, thus subverting the use of the somewhat questionable flow-rate simulation. Once accomplished, the simulation was substantially improved (see Task I). The pattern was shown to be a faithful replication of the flow-rate emanating from the aircraft as properly scaled by the computer program.

The second task developed a new set of computer rules to enable predictions based on the performance of water, Fire-Trol 100, and Fire-Trol 931 (LC-clay thickened). Previously, the simulation handled only Phos-Chek XA (gum thickened) retardant with reasonable predictive confidence. A difference in computer rules was found in the crossrange development portion of the program. New rules in crossrange and a different empirical value of percent recovery were built into the program and good matches were achieved (see Task II).

One other feature (not required by contract) was built into the program as a result of joint effort by Honeywell and the U. S. Forest Service. This was the addition of an optional subroutine (based on an algorithm developed by Max Conner, NFFL) that predicts the interval between tank releases and the resulting maximum line-length achievable from overlapping patterns on the ground under various release conditions (see Task III).

TANK PERFORMANCE DATA COLLECTION

The Guideline generation starts with the collection of flow-rate data on the tanking system to be evaluated. These data are collected using a U. S. Forest Service-designed float-gage that permits recording the drop of the top of the fluid as a function of time in one tank. These data are converted to gallons released as a function of time from an analysis of tank geometry. The gallons-released-as-a-function-of-time table is theoretically all that is required to conduct the subsequent simulation.

Experience has shown, however, that additional data should also be recorded to aid in the interpretation of the flow-rate data if difficulties should arise, and to account for functional pecularities in the tanking system. Two of the four aircraft tanking systems studied in this program required some interpretation of flow-rate data, and this interpretation is greatly assisted when more test information is available. In addition there is some evidence in data examined to date that, for presently unexplained reasons, occasionally a tank evacuates in a substantially different way than its usual, typical flow. Such unexplained anomalies were noted in 4 of 20 CL-215 drops and 1 of 8 S2F drops. The frequency of these anomolies is low enough to be of limited significance in generating guideline data as long as static testing is sufficiently extensive to enable identification of a representative rather than an anomalous flow-rate.

Static test measurements should at a minimum provide:

- Measured flow-rate (head versus time) for a single tank of each geometry represented in the tanking system and for each door option, if more than one door opening area is selectable. A minimum of three tests on each of the above is recommended. If

the three tests do not appear comparable, or abnormal performance is indicated, additional tests should be run. Evidence suggests that testing can be adequately accomplished using water, in that the difference introduced by thickeners can substantially be ignored. (If door opening requires aircraft power, tests should be conducted with the engines running.)

- Multiple-tank flow rates. If the performance of the tanking system changes with the number of tanks released simultaneously, additional tests should be conducted to determine the single-tank flow-rate with each combination of simultaneous tank releases. This condition can occur when all doors open off of the same accumulator (causing the door-opening rate to change as a function of the number of doors operated) or if tanks are vented through a common stack. Both situations can modify the flow rate significantly.

The following additional measurements are recommended:

- Door open angle as a function of time. Although the simulation is capable of including these data in its operation, its effect is negligible when the flow-rate data are known. The data do provide a check on the repeatability of door operation, can assist in the interpretation of results, and will be of potential value in any future refinement of predictive flow-rate simulations.

- Tank pressure as a function of time. The velocity of the air drawn in through the tank vent creates a pressure drop that modifies flow-rate. In extreme underventing, the pressure buildup can halt the fall of the upper fluid surface and cause the tank to evacuate from the bottom in a so-called pop-bottling mode. When this occurs the flow-rate determined by the fall of the fluid

surface in the tank no longer reflects the gallons per second released from the aircraft. Availability of pressure data can provide the basic information to estimate a flow-rate sufficiently accurately for use in the program. (This case was observed in data on the Hemet Valley S2F.) The effects of vent area and resulting pressure will most certainly be included in any future work on flow-rate simulations.

SIMULATION PROGRAM

The simulation program operates as follows:

- Selection of the Typical Flow-Rate – After evaluation of flow-rate, a typical flow-rate is selected for use in the computer-simulated aircraft test plan. If considerable variability of data suggests that a typical run might be misleading, the extremes of performance may also be earmarked for evaluation to assess the sensitivity of these variations to guideline conclusions. In most cases, however, this variation appears to be minor.

- Selection of Aircraft Parameters – The computer test plan is run at an aircraft velocity at the mid-point of its airspeed envelope under delivery conditions. The data can also be generated at high, low, or selected intermediate velocities. The issue in the simulation is aircraft speed with respect to the ground, which is not precisely known in the actual drop situation. Examination of the sensitivity of patterns to delivery velocity suggest that aircraft velocity has less effect on coverage levels of interest than might be supposed. Flying faster generally reduces peak coverage and increases pattern length at low levels. Flying slower tends to increase coverage levels. The uncertainty of

true groundspeed at the time of drop is larger, in general, than the magnitude of pattern change resulting from the selection of a specific aircraft velocity for the drop. Pattern estimates are made at the midpoint aircraft velocity, which is assumed to be true groundspeed. Performance may be somewhat better in an actual drop, but seldom significantly worse, than that shown in the guides. For much the same reason, level flight over flat terrain is assumed, although data in the guides can be easily examined under other terrain/flight path conditions.

- Computer Test Matrix – The recommended schedule of runs for generating guidelines is as follows:

Drop Height (ft)	PATADD	Number of Runs		
100		One of each possible combination of simultaneous tank loads; for example:		
150	X			
200				
250		6-Tank System	1 tank	1 tank
300	X		2 tanks	2 tanks
400			3 tanks	4 tanks
500	X		6 tanks	8 tanks

A second set of runs is generated for any tanks that have alternative door options (such as the Aero Union B-17). One of the above matrices is run for each gum-thickened, and water-like retardant type. The recommended schedule provides a somewhat richer data field than was used in generation of the current guidelines. Depending on the tank, considerably fewer runs can yield adequate data. Nonetheless, in reducing guideline generation to standard practice it is more cost effective to generate a rich data field initially than to re-run specific cases if later

analysis shows additional information is necessary. This results because the computer assembly time is about 10 times the run time for a single test flight (less PATADD option). The PATADD option runs about as long as the assembly time and is consequently specified selectively on only those runs required to generate adequate guideline data.

The foregoing represents a considerable amount of data, some of which is used directly in the generation of user guideline information and some of which is used only as reference. These data (see Appendix A for examples) include the following:

- Detailed pattern plots, used in generating pattern footprints.
- Scaled pattern plots, ignored in the generation of guidelines but useful in visually inspecting the results of a drop.
- Pattern area, length, and gallonages by coverage level summaries. Area divided by length is used to establish pattern width values in pattern footprints. The remainder of the data is for reference and inspection only.
- Maximum-line-length/tank-sequence tables from a subroutine (PATADD). These data are summarized to yield Best-Strategy charts in the guides and are also presented in slightly edited form in the guide.

PREPARATION OF DETAILED GUIDES

General Information

The general information for the detailed guides is a one-page summary of aircraft tanking characteristics. It contains:

- An outline drawing of the aircraft showing the location of the tanking system.
- An isometric sketch of the tanking system with approximate dimensions as a record of tank control options and features. All tanks and their compartments are indicated.
- A summary table of tank characteristics including flow-rate data.
- A narrative summary of aircraft and tanking system performance, tank options, safety considerations, etc.

The illustrations are developed from aircraft and tank geometric data and are intended primarily to enable quick recognition of the subject aircraft and create a general awareness of tanking features.

The table of characteristics, an example of which is shown in Figure 1, is derived entirely from measured flow-rate data:

- Time to evacuate the tank is the time it takes from initiation of release until the bulk fluid drops through the tank door. Some wall drainage continues well after the bulk of the fluid is released. This fluid, though constituting only a few gallons, is easily misleading in attempts to estimate evacuation time visually.

CHARACTERISTICS

Capacity	800 Gallons		
Increment	Four 200-Gallon Tanks		
Tanks Released [1]	Evacuation Time (sec)	Av Flow Rate (gallons/sec)	Peak Flow Rate (gallons/sec)
1	1.0	200	350
2	1.1	360	670
4	1.2	① 670	② 1000

① AVERAGE FLOW-RATE = $\frac{\text{CAPACITY OF TANKS RELEASED}}{\text{EVACUATION TIME}}$

② PEAK FLOW-RATE = PEAK VALUE OF $\frac{DQ}{DT}$ FROM MEASURED FLOW DATA

MEASURED FLOW TABLE

TIME	Q- GALLONS	CALCULATED FLOW-RATE (GALLONS/SEC)	
.1	2.6	132	
.2	15.8	166	
.3	32.4	184	
.4	50.8	193	PEAK FLOW-RATE
.5	70.1	175	≃ 200 GAL/SEC
.6	87.6	$\frac{Q-87.6}{t-0.6}$	
t	Q		

Figure 1. Table of Tanking System Characteristics – Example

- Average flow-rate is simply the number of gallons released divided by the evacuation time. It has the dimensions of gallons per second and is an indicator of the coverage levels generated in the pattern.

- Peak flow-rate is calculated from the measured flow data as the change in gallons with respect to time, $\frac{dQ}{dt}$. For example, see Figure 1.

The narrative summary of performance is generated after complete evaluation of the tanking system. Although the content will vary with each system, in general it includes:

- Aircraft description and tank options
- Key tanking characteristics as they determine the pattern capability and how it is controlled
- Ground safety limits, if any (see below)
- A summary of the Best-Strategy charts, noting the most appropriate ways to employ the tanking system
- Any unique characteristics of the tanking system not already covered

Ground safety limits are from pattern footprints. If the drop produces significant coverage at high levels (greater than 5 gpc) and retains a horizontal velocity vector, the drop pattern is considered potentially dangerous to ground personnel. Since there is little data to relate pattern dynamics definitively to the degree of ground safety, this value is somewhat subjective. A conservative approach should be employed in making these assessments. Where film data are available from actual drops at various altitudes, they can provide considerable additional background for making the ground safety limit assessment.

Pattern Coverage Characteristics (Footprints)

Pattern footprints are a technique of interpolating and displaying pattern performance as a continuous function of drop height. They are generated for each combination of simultaneously released tanks, each door option, and each retardant type, according to the following procedure (see Figure 2):

- Pattern-length data are interpolated by plotting the central pattern cross section from the detailed pattern plots (1) at each drop height of interest (2). Drop heights of 150, 300, and 500 feet are initially adequate. As the development of the footprint progresses, the need to introduce other drop-height data for resolving questionable areas of pattern change may become evident. Plots should be constructed on the same range scale that is to be employed in the footprint.

- Range-length data are then transferred to the drop-height coordinate (3) for each coverage level, 1, 2, 3, 4 or 4+ gallons per 100 square feet (gpc), contained in the cross-section plot. This includes distance of the contour from point of release and length of the contour.

- At zero-drop height, a length is plotted representing aircraft travel during the time of tank evacuation (4). This is calculated by multiplying the aircraft speed by the evacuation time.

- The footprint is then interpolated by fairing in the contour lines (5). It is in this process that clarification of line-fairing points may suggest the use of additional detailed patterns from the test data bank.

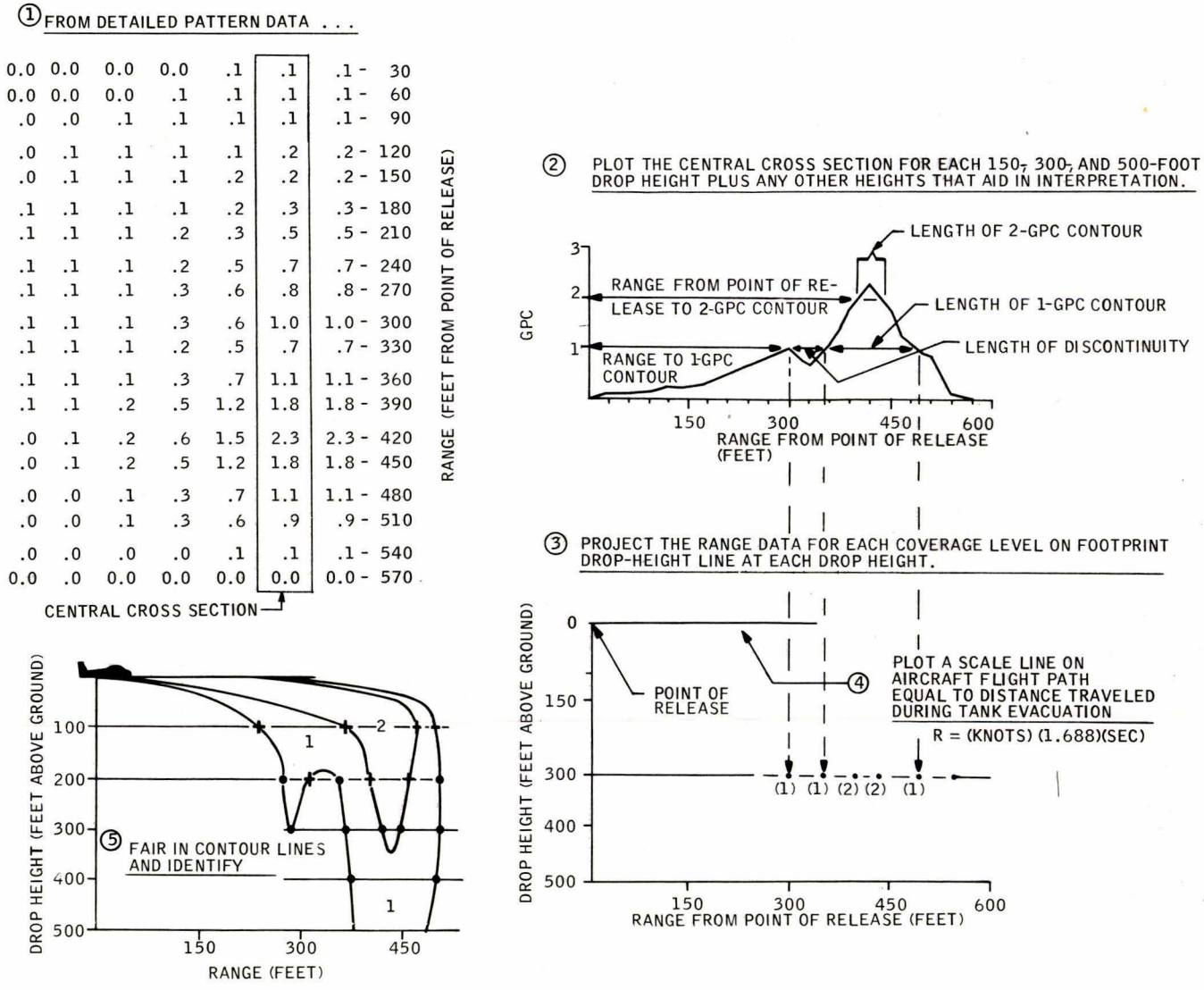

① FROM DETAILED PATTERN DATA . . .
0.0 0.0 0.0 0.0 .1 .1 .1 - 30
0.0 0.0 0.0 .1 .1 .1 .1 - 60
.0 .0 .1 .1 .1 .1 .1 - 90
.0 .1 .1 .1 .1 .2 .2 - 120
.0 .1 .1 .1 .2 .2 .2 - 150
.1 .1 .1 .1 .2 .3 .3 - 180
.1 .1 .1 .2 .3 .5 .5 - 210
.1 .1 .1 .2 .5 .7 .7 - 240
.1 .1 .1 .3 .6 .8 .8 - 270
.1 .1 .1 .3 .6 1.0 1.0 - 300
.1 .1 .1 .2 .5 .7 .7 - 330
.1 .1 .1 .3 .7 1.1 1.1 - 360
.1 .1 .2 .5 1.2 1.8 1.8 - 390
.0 .1 .2 .6 1.5 2.3 2.3 - 420
.0 .1 .2 .5 1.2 1.8 1.8 - 450
.0 .0 .1 .3 .7 1.1 1.1 - 480
.0 .0 .1 .3 .6 .9 .9 - 510
.0 .0 .0 .0 .1 .1 .1 - 540
0.0 .0 0.0 0.0 0.0 0.0 0.0 - 570
CENTRAL CROSS SECTION
RANGE (FEET FROM POINT OF RELEASE)
DROP HEIGHT (FEET ABOVE GROUND)
100
200
300
400
500
150
300
450
RANGE (FEET)
1
2
1
⑤ FAIR IN CONTOUR LINES AND IDENTIFY
② PLOT THE CENTRAL CROSS SECTION FOR EACH 150, 300, AND 500-FOOT DROP HEIGHT PLUS ANY OTHER HEIGHTS THAT AID IN INTERPRETATION.
GPC
3
2
1
RANGE FROM POINT OF RELEASE TO 2-GPC CONTOUR
RANGE TO 1-GPC CONTOUR
LENGTH OF 2-GPC CONTOUR
LENGTH OF 1-GPC CONTOUR
LENGTH OF DISCONTINUITY
150
300
450
600
RANGE FROM POINT OF RELEASE (FEET)
③ PROJECT THE RANGE DATA FOR EACH COVERAGE LEVEL ON FOOTPRINT DROP-HEIGHT LINE AT EACH DROP HEIGHT.
DROP HEIGHT (FEET ABOVE GROUND)
0
150
300
400
500
POINT OF RELEASE
④ PLOT A SCALE LINE ON AIRCRAFT FLIGHT PATH EQUAL TO DISTANCE TRAVELED DURING TANK EVACUATION
R = (KNOTS) (1.688)(SEC)
(1) (1) (2) (2) (1)
150
300
450
600
RANGE FROM POINT OF RELEASE (FEET)

Figure 2. Generation of a Pattern Footprint – Example (at 300-foot drop height)

- Footprint half-width (Figure 3) is calculated for each coverage level/drop height from pattern summary data as follows:

$$\frac{1}{2} \quad \frac{\text{Area above X gpc}}{\text{Length above X gpc}} = \text{Width (feet)}$$

  Area above X is the sum of areas at or greater than X gpc from the PATSIM printout labeled "Contour Intervals for Retardant Distribution (Square-Foot Coverage) – Total Within Each Interval." Pattern length at X gpc is taken directly from "Pattern Length Data."

- The half-width contours are faired in as shown in Figure 3.

- The operation is repeated until a footprint has been developed for each tank combination and retardant type.

Recommended Coverage Levels

A standard table of recommended coverage levels accompanies each set of coverage footprints. This table (see Figure 4) was developed for the guidelines with the guidance of the Northern Forest Fire Laboratory. They are keyed to the nine fuel models of the National Fire Danger Rating System (Ref. 4). The brief, general descriptions of the fuel models were provided by H. Anderson of the NFFL. Coverage-level values were first identified using the concept of Maximum Useful Retardant Concentration (MUC) calculated by Rothermel and Philpot (Ref. 5).

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION
(SQUARE-FOOT COVERAGE)
TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0
46800	24300	8100	5400	1800	2700	0	0	0

8.1-9.0	9.1-10		
0	0	TOTAL AREA COVERED	89100 SQUARE FEET

> 10
0

PATTERN LENGTH DATA

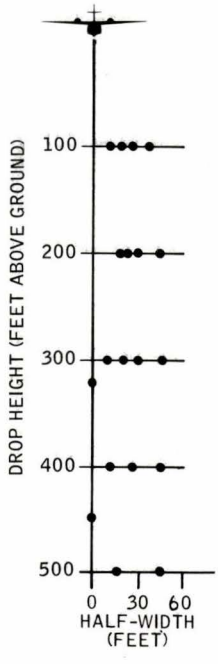
480 FEET ABOVE	0.0 GALLONS/100 SQUARE FEET
330 FEET ABOVE	.3 GALLONS/100 SQUARE FEET
240 FEET ABOVE	1.0 GALLONS/100 SQUARE FEET
210 FEET ABOVE	2.0 GALLONS/100 SQUARE FEET
120 FEET ABOVE	3.0 GALLONS/100 SQUARE FEET
90 FEET ABOVE	4.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	5.0 GALLONS/100 SQUARE FEET

① FROM PATTERN SUMMARY DATA, ABOVE, CALCULATE HALF-WIDTH FOR EACH COVERAGE LEVEL AND DROP HEIGHT AS:

$$\text{PATTERN HALF-WIDTH} = \frac{1}{2}\,\frac{\Sigma\ \text{AREA ABOVE} \times \text{gpc}}{\text{LENGTH ABOVE} \times \text{gpc}}$$

② GRAPH THE COMPUTATIONAL RESULTS AT EACH ALTITUDE →

gpc	AREA ABOVE	LENGTH ABOVE	HALF-WIDTH
1	18000	240	38
2	9900	210	24
3	4500	120	19
4	2700	90	15



③ FAIR-IN AND IDENTIFY CONTOUR LINES

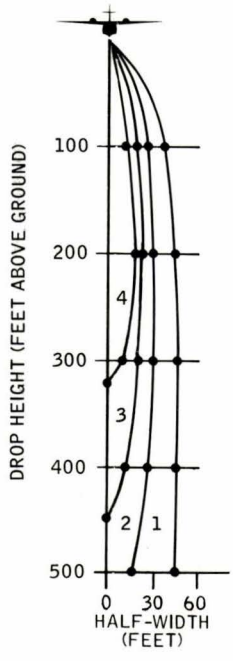


Figure 3. Generation of a Pattern Half-Width Footprint – Example

Coverage Level	Recommended For:	
	Fuel Model	Description
1	A	Grasses; tundra, and open desert shrub lands
2	C	Conifer timber with grass understory
	F	Brushfields with much green material
3	D	Shrublands under 6 feet in height (such as sagebrush)
	E	Hardwood litter after leaf drop
	H	Closed conifer timber with litter only
4	B	Hard chaparral and other high (6-foot) flammable shrubs
	G	Closed, old conifer timber with litter and dead, down limb wood.
	I	Conifer slash

For creeping or smouldering fires reduction of one coverage level may be considered.

Figure 4. Recommended Coverage Levels (expressed in gallons per 100 square feet)

Basically, Rothermel showed that there is a theoretical maximum useful salt concentration that will drive the nondimensional propagating flux, η_r, to zero, and that when differences in the retardant salt and density are taken into account, this maximum value can be expressed as a single, simple relationship to the fuel loading, W_o, the fuel particle size, and the gross fat content of the fuel. Rothermel calculated the MUC value for 11 discrete fuel models that are directly relatable to the more general 8 models contained in the NFDRS. Table 1 shows these values.

In subsequent correspondence (Ref. 6), Rothermel added to the computation the feature of retardant-film thickness. The equivalent film thickness concept comes from work originated by Grah and Wilson (Ref. 7), and was used in determining capacities of vertical fuel models in Reference 2. The required film thickness needed to stop a fire was shown to be a function of particle size and gross fat content. This modification changed the MUC values slightly and is also shown in Table 1.

Table 1. Values of the Maximum Useful Retardant Concentration

Fuel	Total gpc[a]	Total gpc[b]	Related Fire Danger Rating Model[c]
Short Grass	0.69	0.63	A
Tall Grass	2.60	2.60	D
Brush	1.80	2.16	F
Chaparral	10.00	8.33	B
Timber, Grass and Understory	2.60	1.98	C
Timber Litter	1.60	2.24	H
Timber Litter and Understory	5.00	4.38	G
Hardwood Litter	2.80	2.65	E
Logging Slash, Light	2.60	1.98	-
Logging Slash, Medium	7.50	5.63	I
Logging Slash, Heavy	13.00	9.60	-

[a] Reducing Fire Spread in Wild Land Fuels, Rothermel, R. C., and Philpot, C., Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, July 1974 (Ref. 5)

[b] Letter, Rothermel to Swanson, 17 October 1974 (Ref. 6) Considers effect of Retardant Film Thickness

[c] National Fire Danger Rating System, Deeming et al, USDA Forest Service Research Paper RM-84, February 1972, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado (Ref. 4)

From the revised values of Maximum Useful Retardant Concentration, the recommended coverage levels were assigned, and the resulting recommendations were then evaluated from several other viewpoints:

- Credibility of the recommended values based on field experience: Air tankers of known pattern-generating capabilities have been used in specific ways effectively against many of the fuel types. Notably, 1 gallon per hundred square feet or less appears effective in trail systems that are acknowledged favorites against grass fires. Similarly, TBMs providing coverage of 1 to 4 gpc have been used effectively against most of the fires involved.

- Fuel capacities: Considerable data on the capacities of vegetation were collected from reference material in the High Altitude Retardant Drop Mechanization Study (Ref. 2). These show the ability of various vegetation to hold water on their surfaces. When the surface capacity is saturated, any additional in-flow turns to ineffective runoff. These values (Table 2) are also commensurate with those of recommended coverage.

- Fuel index relevance numbers: The fire danger rating for a particular fuel makes use of nondimensional numbers on a scale of 0 to 100 to quantify potential fire situations. Two of these index ratings can be construed as relevant to the coverage-level problem. The first of these is the "Burning Index", a number related to the amount of effort needed to contain a fire in fuels represented by the model. This appears to be a flame-length parameter but it has, in a qualitative sense, the dimensions of Byram's Intensity; i.e., it is a function of a spread component and an energy release component. Thus we might expect the values representing difficulty to differentiate between fuel models in the same order as the coverage levels. This contention appears to be true as shown in Table 3.

Table 2. Some Fuel Water Capacities

Vegetation Element	Species	Storage Amount (mm)	Storage Amount (in.)	Reference	Equivalent Coverage, (gal./100 ft^2)
Conifers	Pinus contorta Dougl.	0.8	0.03	Niederhof and Wilm (1943)	1.9
	Pinus lambertiana Dougl.				
	Pinus ponderosa Laws.	3.0	0.12	Rowe and Hendrix (1951)	7.5
		0.8-1.3	0.03-0.05	Johnson (1942)	1.8 → 3.1
	Pinus radiata D. Don	0.3-0.1	0.01-0.04[t]	Grah and Wilson (1949)	.6 → 2.5
	Pinus resinosa Ait.	0.8	0.03	Voight and Zwolinski (1964)	1.9
	Pinus strobus L.	0.5	0.02	Voight and Zwolinski (1964)	1.3
	Tsuga canadensis (L.) Carr.	0.8-1.3	0.03-0.05	Horton (1919)	1.9 → 3
Hardwoods	Aesculus californica (Spach) Nutt.				
	Fall and winter	0.8	0.03		1.9
	Spring and summer	1.3	0.05	Hamilton and Rowe (1949)	3.
	Citrus aurantium L.		0.04	Blaney et al. (1930)	2.5
	Mixed hardwoods (Acer, Ulmus, Quercus, Betula)	0.5-1.8	0.02-0.07	Horton (1919)	1.3 → 4.4
	Mixed hardwoods - West Virginia				
	Quercus rubra L., Liriodendron tulipifera L., etc.)				
	Summer	0.5	0.02		1.3
	Winter	0.2	0.006	Trimble and Weitzman (1954)	.4
	Northern hardwoods	2.0	0.08	Morey in Johnson (1942)	5
	Liquidamber Styraciflua L.	0.8	0.03[t]	Paul and Burgy (1961)	1.9
	All eastern N. American hardwood data	0.03-1.6	0.001-0.064	Helvey and Patric (1965)	.1 → 4
Shrubs	Adenostoma fascriculatum H & A	1.3 -1.5	0.05-0.06[t]	Hicks (1943)	3 → 3.7
	Baccharis pitularis DC.	0.5 -1.5	0.02-0.06[t]	Grah and Wilson (1944)	1.2 → 3.7
	Ceanothu cuneatus (Hook) Nutt.,				
	Arctostaphylos mariposa Dudley	1.5	0.06	Hamilton and Rowe (1949)	3.7
	Cercocarpus ledifolius Nutt.,	1.0	0.04[t]	Hicks (1943)	2.5
	Photinia arbutifolia Lindl.	0.3 -1.8	0.01-0.07	Hicks (1943)	.6 → 4.4
	Quercus dumosa Nutt.,				
	Cereocarpus betuliodes Nutt.,				
	Ceanothus crassifolius	2.0	0.08	Hamilton and Rowe (1949)	5

Table 3. Comparison of Recommended Coverage Levels with Fire Danger Rating Indices

Fuel Model	Energy Release Component[a]	Burning Index[a]	Coverage Levels
A	19	12	1
	L	L	L
B	100	100	4+
	H	H	H
C	34	41	2
	M	MH	ML
D	31	51	3
	M	MH	MH
E	36	22	3
	M	ML	MH
F	11	8	2
	L	L	ML
G	85	58	4+
	H	MH	H
H	34	27	3
	M	MH	MH
I	96	90	4+
	H	H	H

[a] L = Low; M = Medium; H = High

A second value of interest in Table 3 is the "Energy Release Component" which is based on the fine fuel moisture content. Since the effect of the moisture content of the retardant acts most directly as an increase in the fuel moisture, this value could be construed as a relative difficulty of containment by water alone. Again the index values related closely to the relative ordering of recommended coverage levels.

One fuel model is a notable exception in the above evaluation. Fuel model F appears high in the MUC value as compared to the low ranking in the NFDRS, relevance numbers. The description states that there is a considerable amount of green material in the brushfield, which implies the fuel may contain a high percent of its moisture of extinction. At the same time it has a moderate gross fat content (F_g = .03). Since these two values are indicative of the leverage the retardant water content and salt, respectively, can exert on the fire, it suggests that an alternative MUC value based on water content might reduce the recommended coverage. The recommended coverage was not changed, however, and this was primarily due to the mitigating factors of the vertical fuel structure and its surface area -- to saturate the fuels so that near uniformity of coverage exists can require more than the theoretically minimum required on the fire.

The recommended coverage levels are nominal values that are generally conservative except at Level 4, which can be construed to represent a heavy coverage rather than a precise value. The values ignore physical breakdown of the fuels, like crushing the grass, which works against the fuel packing ratio mechanically.

Departures from the whole-number values are not in themselves significant. Patterns are blends of coverage levels, not discrete areas.

In like manner, the effect of slightly smaller or greater values on the fire are not in themselves critical. The important point is that the amount of retardant required is limited by physical and chemical considerations, and that quantities much in excess of the values recommended are not as effectively used as if they were distributed over greater area or length in the pattern.

Best-Strategy Charts

Best-Strategy Charts are graphic summaries of the tables generated using the PATADD option to the computer program. The PATADD subroutine yields, for each drop-height condition, a tabular set of values showing the maximum line length and appropriate delay between tank releases for each possible combination of tanks. Although these tables are presented in their entirety as the final section of the guides, considerable study can be required to identify the best of all possible alternatives.

The procedure for generating the Best-Strategy Charts is described in terms of the following example:

- Select the coverage level of interest from the PATADD-generated table (Figure 5). Regroup the tabular data in terms of the fraction of the load to be released. This results in a new table that allows ready identification of the optimum usage. It is usually achieved with a pattern composed of the optimum sequencing of drops.

- On a scale of drop height versus desired line length, plot the optimum strategy lines for each fraction of the load. This is done initially without regard for the designated time interval (see Figure 6).

NO. OF TANKS RELEASED AT A TIME	DROP HEIGHT (FT)	NO. OF PATTERNS	LEVEL 2, 2.0 GPC: MAX LENGTH (FT)	LEVEL 2, 2.0 GPC: DELAY (SEC)
1 TANK	150	1	90	0.0
		2	255	0.8
		4	580	0.8
		8	1220	0.8
	300	1	--	--
		2	145	0.5
		4	360	0.5
		8	805	0.6
	500	1	--	--
		2	50	0.0
		4	180	0.3
		8	455	0.4
2 TANKS	150	1	210	0.0
		2	505	1.5
		4	1105	1.5
	300	1	110	0.0
		2	285	0.8
		4	640	0.9
	500	1	40	0.0
		2	195	0.6
		4	445	0.6
4 TANKS	150	1	360	0.0
		2	745	2.0
	300	1	275	0.0
		2	605	1.6
	500	1	125	0.0
		2	330	0.6
8 TANKS	150	1	390	0.0
	300	1	415	0.0
	500	1	300	0.0
	700	1	295	0.0
	1000	1	255	0.0

1. BASIC TABLE FROM PATADD SUBROUTINE

2. IS RETABULATED TO IDENTIFY MAXIMUM LINE FOR EACH LOAD FRACTION AND DROP HEIGHT

	150FT	300FT	500FT
→ 8 TANKS, 1 AT A TIME	1220;.8	805;.6	455;.4
8 TANKS, 2 AT A TIME	1105;1.5	640;.9	445;.6
8 TANKS, 4 AT A TIME	745;2.0	605;1.6	330;.6
8 TANKS, 8 AT A TIME	390;0	415;0	300; 0
→ 4 TANKS, 1 AT A TIME	580;.8	360;.5	180;.5
4 TANKS, 2 AT A TIME	505;1.5	285;.8	195;.6
4 TANKS, 4AT A TIME	360;0	275;0	126;0
→ 2 TANKS, 1 AT A TIME	255;.8	145;.5	50;0
2 TANKS, 2 AT A TIME	210;0	110;0	40;0
→ 1 TANK, 1 TIME	90;0		

3. RESULTS ARE GRAPHED AS SHOWN IN FIGURE 6

NOTE THE MAXIMUM LINE USING A FULL LOAD OCCURS WITH THE PROPER SPACING OF SINGLE-TANK RELEASES

Figure 5. Derivation of Basic Data for Best-Strategy Charts

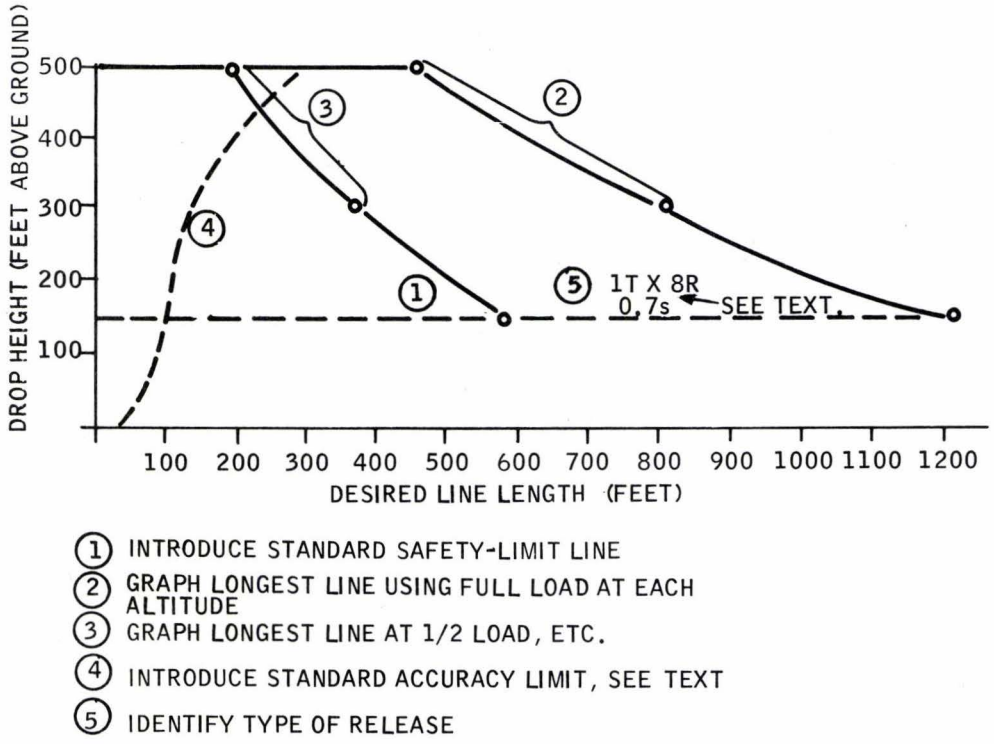


Figure 6. Generation of a Best-Strategy Chart – Example

- Identify each area with the appropriate code; here 1T x 8R (one tank, eight sequential releases) is used to indicate the best approach.

- Assign a nominal time interval to the best strategy line. The time interval associated with the maximum line length is presented with an accuracy (0.1 second) that is difficult to use in most aircraft. Note also that it may vary considerably as a function of flight condition values that are not well known -- drop height and aircraft speed with respect to ground, for example. To assign a nominal delay time, it is helpful to examine the recommended optimum times for coverage levels on either side of the level at issue under the same delivery conditions. For the example case:

Drop Height (ft)	Coverage Level (gpc) 1	2	3
150	1.5	.8	.7
300	.9	.6	.4
500	.7	.4	.2

In this case a 0.7-second nominal delay would assure holding the pattern between 1 and 3 gpc over the altitude range. The nominal delay should be interpreted as "about" 0.7 second. Note that aircraft without intervalometers, or aircraft with sequence controllers not accurately settable, must employ far more approximate values. Although precise values are available from the tables, pilot decision must be guided by the approximate values. The point of the nominal delay is to indicate the appropriate ballpark. In this case, something less than a second.

Standard material associated with the Best-Stragegy charts includes:

- Safety Limit: The safety limit for the aircraft is arbitrarily drawn at 150 feet. At this drop height the retardant cloud is formed for most aircraft drops. Actual safety clearances are referenced with respect to geological high points or the top of the fuels, not with respect to ground. The line is thus a nominal reference.

- Ground Safety Notes: Rigorous definition of the hazard of air-dropped retardants is not as yet possible. The possibility that a drop will injure personnel is related to the extent of retardant breakup and its momentum. If breakup is complete, the pattern has the characteristics of a driving rain and is not particularly dangerous. If breakup is incomplete it is clearly dangerous. The scalar indicators of safety are related to two values -- quantity and the amount of aircraft forward momentum retained. When the pattern footprints show that the pattern has lost its forward velocity and that peak coverage levels do not have significant areas much above 5 gpc, the pattern is assumed to represent no abnormal safety limits. No safety notes are added. When the footprints indicate a forward velocity component with a high peak coverage level, the nearest altitude above the forward velocity decay point is noted -- viz. "Avoid use below 200 feet." Reference to the detailed pattern plots is helpful in this regard. A significant pattern content of 8 to 10 gpc can be construed as hazardous even though the forward velocity has substantially decayed.

- Accuracy Limits: The accuracy-limit line is common to all aircraft charts. It corresponds to a curve defined by setting the probability of hit at 0.6 (no-wind condition) and evaluating the

length of the range error against the length of the pattern. Under actual drop conditions, considering wind, for example, the probability of hit will be considerably less. The limit line thus denotes an area beyond which, in most cases, we have little chance to place the pattern accurately (see Figure 7). Derivation of the curves is given in Appendix B.

Since the standard curve ignores pattern width, which is relatively constant for full-tank drops, it is arbitrarily modified in the trail drop instance where considerably thinner patterns are generated. This arbitrary change simply moves the 300-foot length limit, normally at the 500-foot drop height, to the 300-foot drop height.

Detailed Tables

The detailed tabular section of the guidelines is a direct reformatting of the tables generated by the PATADD subroutine.

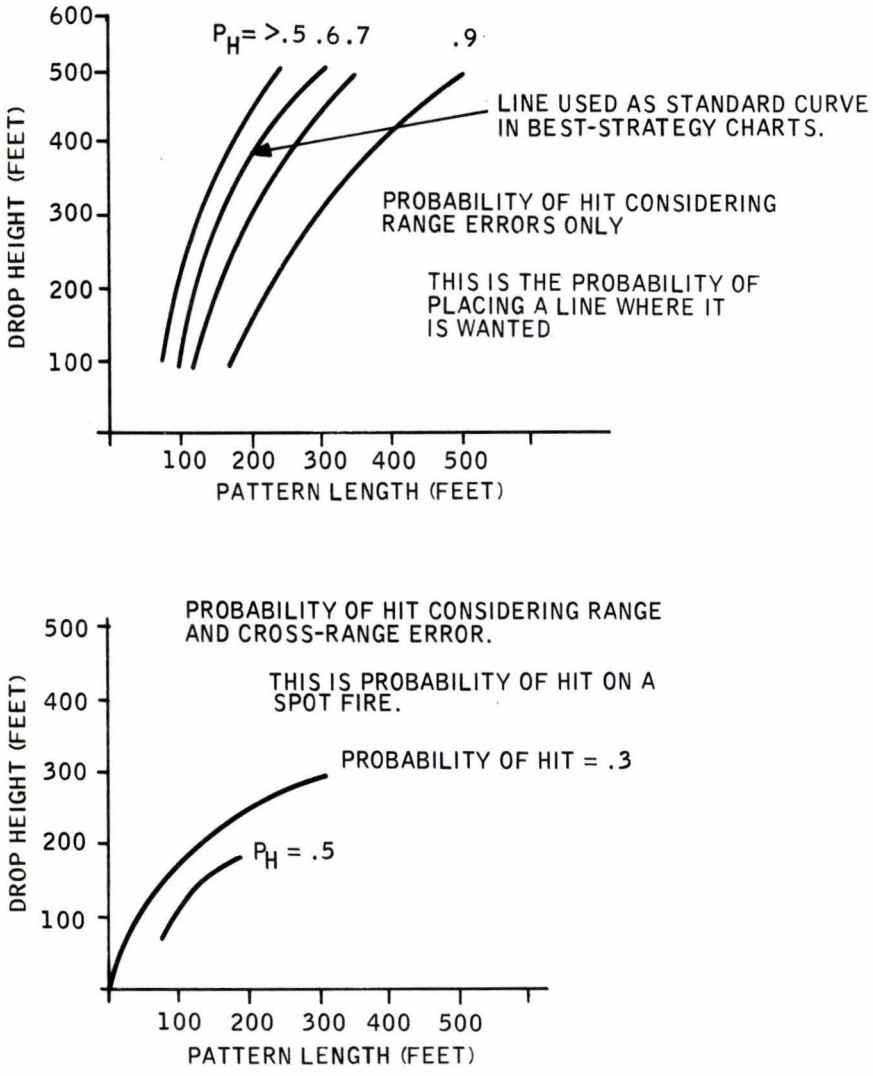


Figure 7. Probability of Hit as a Function of Pattern Length

SECTION III

TASK I - DIRECT FLOW-RATE INPUT TO THE HONEYWELL SIMULATION

Task I of the contract was stated as:

> " Modify the Honeywell Retardant Drop Simulation (MIX 2) to facilitate direct input of measured flow-rate data. "

This task required that the MIX 2 program input section be adapted to accept measured flow-rate as a direct input rather than input the flow-rate predicted from tank geometry and door opening inputs. It thus would reduce the complexity of geometric inputs and allow the simulation to handle special cases where flow irregularities caused by venting or other problems are encountered. The input form could be the derivative of flow and the exit velocity of similar parameters as determined through the reduction of measurement data.

Both the MIX 2 (research) and the PATSIM (operational) simulations of retardant performance employed Bernouli simulation of flow-rate from the tank. With the availability of measured flow data, readily obtained from USFS static ground tests, this greatly simplified technique of estimating flow-rate can be avoided by using measured data. As a consequence, Task I was conducted to introduce this feature to the two programs. A secondary critical issue was to confirm that the program thus modified would continue to exhibit predictive capabilities that had previously been demonstrated for the artificial flow-rate situation.

RESULTS AND CONCLUSIONS

Both MIX 2 and PATSIM programs were modified to accept measured tank flow-rate in tabular form. The PATSIM program (Task III) will run with minimum input in the basic mode using only tabular flow data and allowing the use of door-angle data to compute ejection velocity as an option. The program interpolates coarse tabular data to appropriate computation intervals and extrapolates from the last measured data point (gallons) to the tank capacity.

Simulated patterns using measured flow data were compared with actual drop data for the CL-215 using MIX-2 with RETARD. Match characteristics were considerably improved over those previously obtained using predicted flow-rate values. In particular, the simulated pattern faithfully replicates the mountainous appearance of the 3-D representation, preserves the Weibul characteristics of the actual pattern and improves the match strikingly in several statistical ways. There is, however, a slight fore-shortening of pattern length characteristics (on the order of one data space, about 30 feet) which results partially from the selection of simulation output grid when considerably less simulation accuracy was anticipated. None of the calibration constants was changed in preserving the match with the simulation.

Similar results were indicated in checking the program against DC6B drop data, but these results were not conclusive in that measured flow data did not cover the last one-third of the tank evacuation which occurred over a tank geometric change.

The simulation modified to accept measured flow data is remarkably accurate in recreating a pattern on the ground. Although improvements can be identified in the long range, they are not necessary for the objectives of the current contract. Even the changes are related

to the fact that the simulation is apparently capable of a resolution accuracy far beyond what was thought possible at the time the models were framed. Most significantly the flow-rate from the tank and the specific rheology of the retardant system dominate pattern formation. The intermediate events between release and formation of the ground pattern are relatively invariant and repeatable.

PROGRAM CHANGES

Changes in program input and in the calculations for both MIX 2 and PATSIM were installed as options so the programs can still be run in the old way. The new input added is Q as a function of time and (optionally) TMPS as a function of time. The new calculations are for Q (flow rate) and CONVEX (exit velocity). The exit velocity requires an intermediate step of calculating the door opening area, AOPEN. If door area values (ELE and B) are omitted, and no ejection velocity (CONVEX) is entered, a 16-fps average is automatically employed. The program will run with little effect on the resulting simulation. Door rate data are not required in this case (see Task III).

The following paragraphs summarize changes in the two programs which can be referenced in terms of additions to the program description in Reference 3.

New PATSIM Input

The PATSIM inputs, RDQV and CONVEX, are described in Table 4 and discussed in the following paragraphs.

Table 4. PATSIM Input Options

Variable Number	Variable Name	Description	Initial Value	Units
24	RDQV	Flag to select the option for input Q vs T. Also the number of entries in this table (see discussion below)	0[a]	--
25	CONVEX (Optional)	Constant exit velocity if this option is used. Otherwise, use 0. (No input)	0	ft/sec

[a] If RDQV is set at negative, the program will employ the set tabular increments. Otherwise, the program will interpolate input data to the 0.02-second time increments on which the program runs.

When this new PATSIM input option is used, the RDQV variable must be on one card and the Q-versus-T table must immediately follow this card. There is one table entry per card as follows:

Column	1-10	-	Time, sec.
Column	11-20	-	Q, retardant quantity, gallons
Column	21-30	-	TMPS, door opening angle, degrees. If TMPS values are entered as zero, the original program options are used, i.e., constant door opening rate or cubic equation fit to test data.

The number of cards in this table is equal to RDQV.

Flow-Rate Computations -- The time-step size used in the input table may differ from the time-step size employed by the program. The program has therefore been modified to include a subroutine to interpolate from the input interval to the 0.02-second program interval,

and to extrapolate linearly from the last two tabular entries to the gallon capacity of the tank, GALI, whenever RDQV is entered as a positive number. (This step was critical in early runs, since ΔT in the computation $\dot{Q} \times \Delta T$ = Retardant Out during the interval was set at the computation interval, 0.02 second. The value ΔT has since been redefined as $t_i - t_{i-1}$, allowing use of the measured intervals directly.) The program can be forced to accept the test data interval by entering RDQV as a negative number. This is useful if measured data are at intervals less than 0.02 second or if exceedingly low and constant flow rates persist for considerable time as in some trail drops.

Flow rate is calculated from the tabular entries as

$$\dot{Q}_n = (Q_n - Q_{n-1})(T_n - T_{n-1}) = \text{flow rate (gallons/sec)}$$

Ejection Velocity -- Fluid ejection velocity does not appear to be a critical entry. As a consequence, door opening rate and area may be omitted from the program with little effect on predictive accuracy. (In this case a nominal 16 fps is employed.) Where door rate data are included it may be input, and the computational capability is included for several options.

In the original simulation, the ejection velocity served as both (1) a downward initial velocity for the generation of the range marginal distribution and (2) an intermediate calculation for computing flow rate; i.e., (velocity X open area = cubic feet of retardant/sec). Where actual flow data are available, the second calculation is unnecessary -- indeed, it is reversed to compute the ejection velocity for use in the first calculation. Examination of the effect of various ejection velocity approximations shows little influence on pattern performance. Where door rate data are available, the following computations are provided.

Tabular data (columns 21-30) are used with door area inputs (B and ELE) as shown in Figure 8. The door-open angle TMPS is the average value over the input interval. The resultant computed velocities (Figure 9) show this approximation in relationship to other techniques of handling the velocity. Runs using each of the tabulated assumptions produced only minor variations in the pattern. This is not surprising in that the major effect (on trajectory) of differing downward initial velocities is minimal. As a consequence no refinement of this procedure is considered necessary at this time.

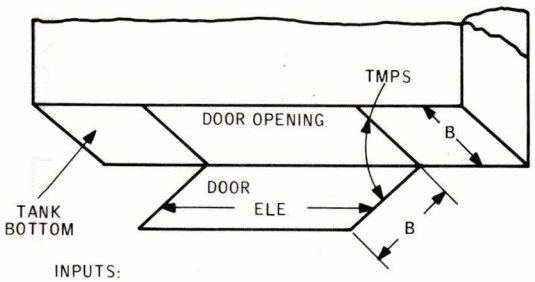
New MIX 2 Input

A new variable is added to input card 1, Col. 71-30. This is RDQVF, a flag used to select the option for input Q versus T. If RDQVF > 0, the Q versus T is input. If RDQVF = 0 the program runs the old way.

Another variable is added to input card 5, Col. 71-80. This is CONVEX, a constant exit velocity. Use CONVEX = 0 to run the old way.

The Q-versus-T table follows input card 5 (if RDQVF > 0). The first card of this table contains RDQV (in Col. 1-10), the number of entries in the table. There is one table entry per card as follows:

Column	1-10	-	Time, sec.
Column	11-20	-	Q, retardant quantity, gallons
Column	21-30	-	TMPS, door opening angle, degrees. If TMPS values are entered as zero, the original program options are used, i. e., constant door opening rate or the cubic equation fit to test data.



INPUTS:

DOOR GEOMETRY	B	= DOOR WIDTH (FT)
	ELE	= DOOR LENGTH (FT)
TABULAR DATA	TIM	= TIME (SECOND)
FROM STATIC TESTS	Q	= RETARDANT QUANTITY (GALLONS)
	TMPS	= DOOR OPENING ANGLE (DEGREES)

COMPUTATIONS:

Q_n = $(Q_n - Q_{n-1}) / (T_n - T_{n-1})$ = FLOW RATE (GALLONS/SEC)

AOPEN = ELE * (2*B*SIN [$TMPS_n$ /2]) = TANK OPEN AREA (FT^2)

(THIS IGNORES THE ENDS)

VEX_n = Q_n / $AOPEN_n$ = EJECTION VELOCITY (FPS)

NOTE: n REFERS TO TIME STEP

Figure 8. Program Changes to Accept Measured Flow Rate and Door Angle

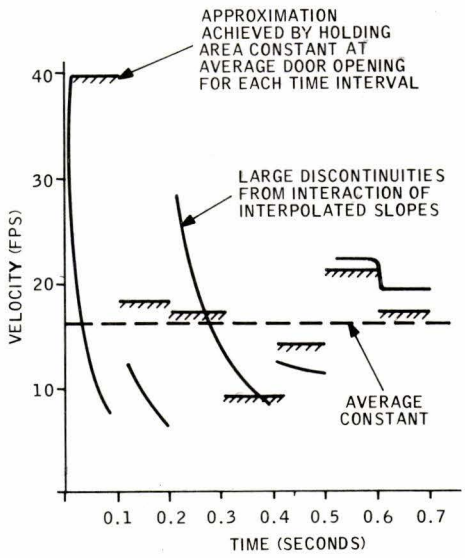


Figure 9. Tank Ejection Velocity Predicted Using Different Programming Algorithms

CL-215 CHECKOUT

The program as modified to accept flow data was checked out using the CL-215 in the MIX 2 simulation as compared with actual pattern data. The following paragraphs present the results of this study.

CL-215 Measured Flow Data

Measured flow data collected and reduced by the Forest Service were examined to determine the effect of the apparent variability of data (either in the tank or resulting from the instrumentation) on simulated pattern performance. It was also desired to select a representative flow for use in the water calibration task. Table 5 shows the data as tabulated by the Forest Service for a series of three test drops. In discussions with Max Conner, it was determined that there is some ambiguity in the starting point for the drop both from the standpoint of reading the oscilloscope traces and starting inertia or slack in the float instrumentation. To minimize the effect of this uncertainty, the drops were plotted on a relative time scale to coincide at the point where 350 gallons were evacuated. Figure 10 shows resulting curves for the three single-tank drops in relationship to a shaded band containing all the drop data. The graph shows that results are reasonably repeatable, provide generally the same form, and can be represented by a typical flow rate with reasonable certainty. Only drop 5-14 showed some evidence of anomalous behaviour in the last 200-gallon increment.

From this analysis, two flow tests were selected to represent the variability that might be encountered in drops from essentially the same tank. These were, drops 2-14 and 1-14, which were run in a test simulation against actual pattern data for CL-215 drop 4, from 300 feet.

Table 5. Measured Flow Data

Time (sec)	Test 1-14		Test 2-14	
	Quantity (gal)	Angle (deg)	Quantity (gal)	Angle (deg)
.0	0	0	0	0
.1	17	5	0	10
.2	47	14	12	20
.3	123	37	61	40
.4	190	51	113	57
.5	317	57	202	
.6	516		352	
.675	641			
.7			619	
.715			659	

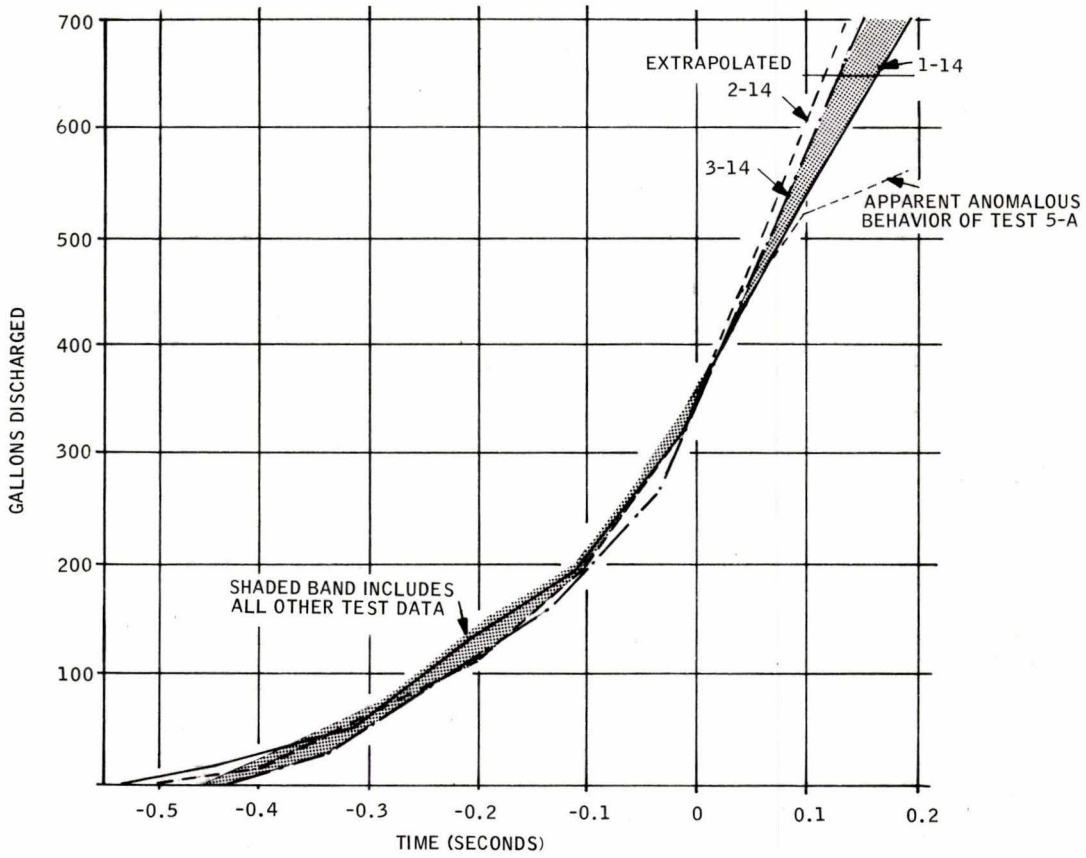


Figure 10. Variability of Measured Flow Data

Figure 11 shows the computed flow rates. No attempt was made to smooth this curve in the program, and the results appear to adequately represent the real patterns without further refinement.

Results

Pattern comparisons were made using several different techniques of evaluation for each of the two flow-data cases as compared with CL-215 drop 4. The results show generally that the simulation from flow-rate data matches the real pattern in a statistical sense far better than had been achieved previously even though none of the calibration constants inherent in the model was changed. The reason for this is also relatively clear: the flow-rate distribution so dominates the pattern formation process that it is relatively insensitive to subordinate parameters other than aircraft velocity and altitude. The effects of other factors, if any, would be difficult to resolve without drop data from calibrated tanks (ETG system). The single deficiency indicated in the study of results is a tendency to underestimate pattern length which can presumably be traced to certain assumptions in the crossrange distributional scheme. For purposes of the User Guideline study it appears sufficient to recognize this error as a bias (about 30 feet, or one square) to achieve reasonable correlation of length.

The following paragraphs discuss each pattern comparison.

3-D Plots -- The subjective similarity between the simulated and actual patterns is shown in the 3-D plot comparisons of Figures 12 and 13. The striking discovery is that the peaked nature of the pattern is now preserved in the simulation, a condition that was previously thought to be unlikely in that simulations are typically averages in achieving matches. This leads to the tentative conclusion emphasized in further investigation that the pattern is a faithful reproduction of the flow-rate

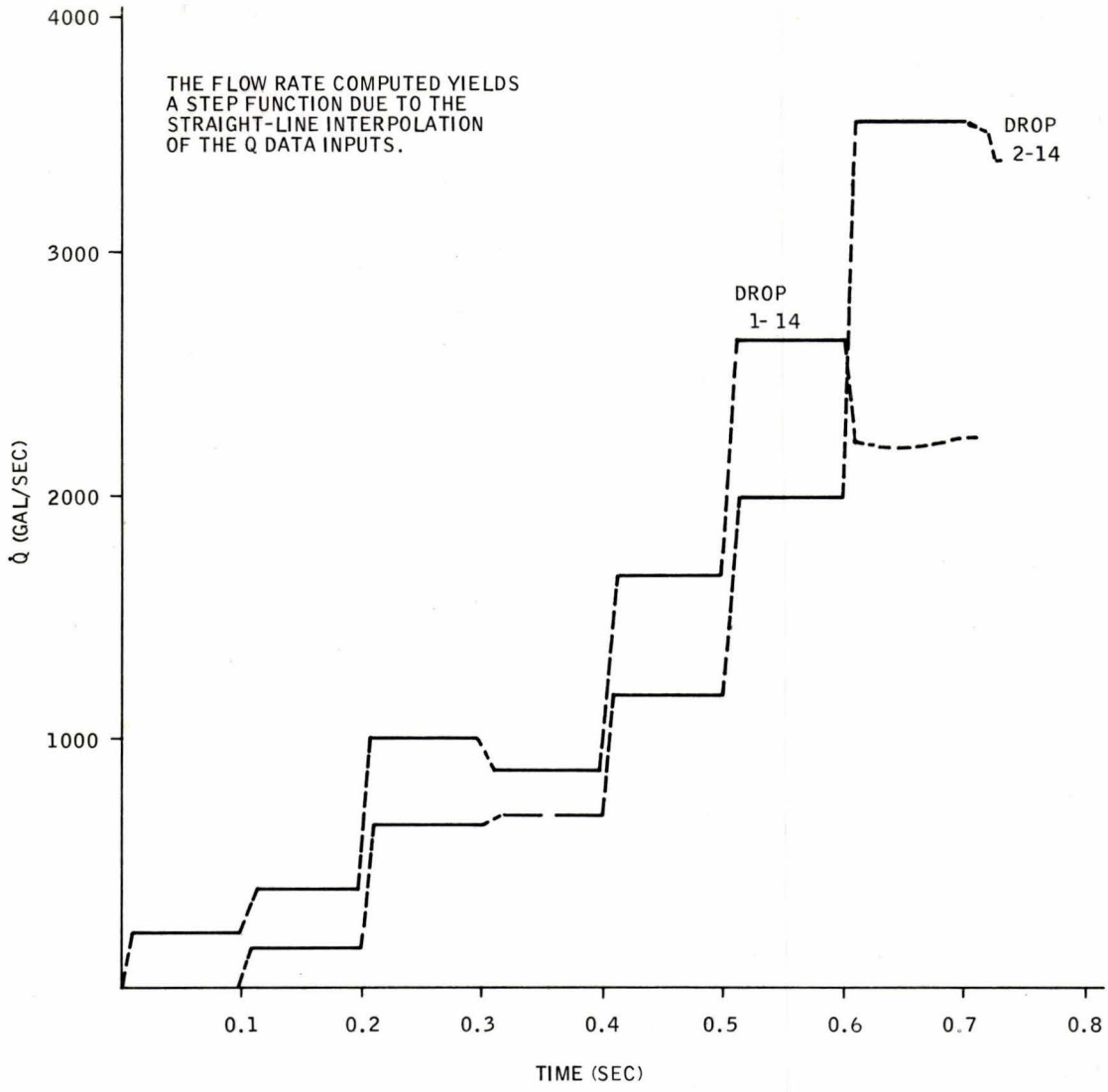


Figure 11. Computed Flow-Rates

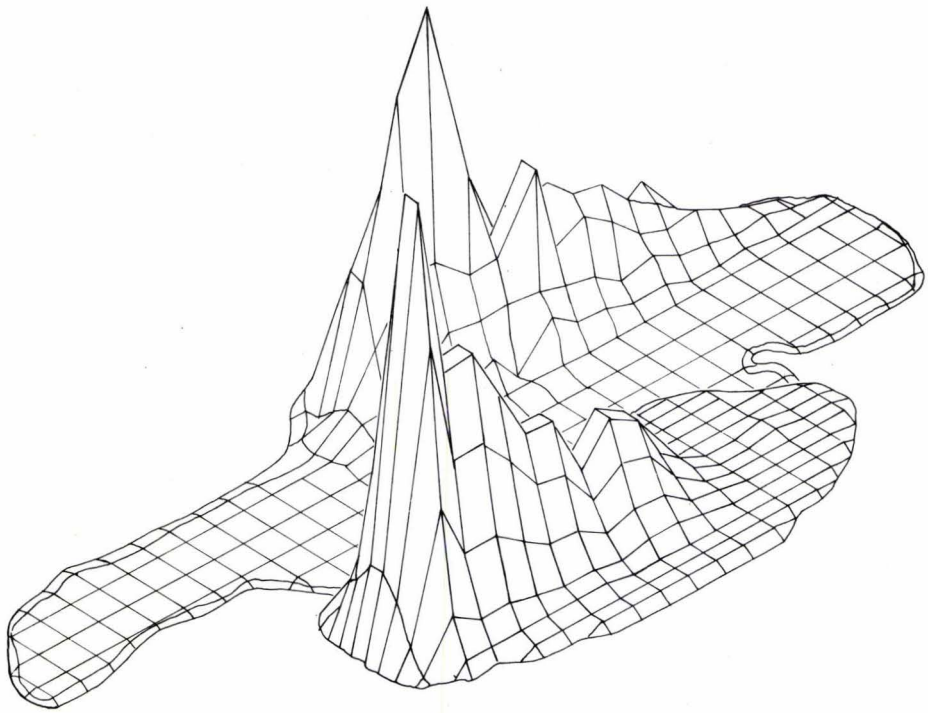


Figure 12. Simulation of Flow Test 2-14 Compared with Drop 4 Pattern

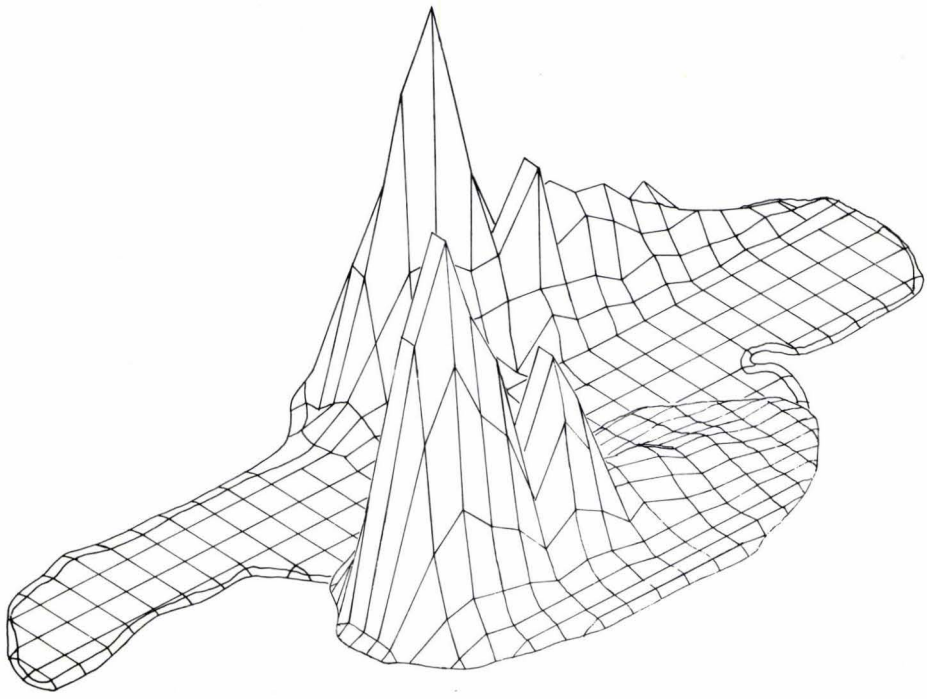


Figure 13. Simulation of Flow Test 1-14 Compared with Drop 4 Pattern

from the tank. It appears likely that somewhere within the band of measured flow rates a unique perfect match to the pattern could be hypothetically generated.

Pattern Cross Section -- The preservation of the flow-rate feature is somewhat more quantitatively evidenced in the pattern cross sections of Figures 14 and 15. These cross sections are elevation views of the pattern in that they represent the highest value of each row across the pattern. For the simulation, this is the central conditional distribution. The technique eliminates the subjectiveness of identifying a hypothetical central cross section of real pattern data.

Area Match -- The statistics of the area match (and gallonage) are presented in Table 6. Both simulations achieved lower variance values than had been previously obtained. The curve of Figure 16 shows the significant area match as a band of uncertainty related to the actual pattern statistics. The crossover of the two simulation values lends credance to the contention that the actual pattern was generated by a flow resembling 2-14 in the earlier stages of release and 1-14 in the latter stages.

Weibul Characteristics -- It is interesting to note that the Weibul distribution characteristics previously identified as relevant to real patterns are now reasonably preserved in the simulation as shown in Figure 17.

Power Around the Variance -- Fourier analysis of the difference data in the two drops (Figure 18) shows that the difference has been reduced to what passes in most analyses as noise; i. e., there is little if any coherent frequency in the deviations about the variance. Let us examine this a bit more, since further study supports the contention that flow-rate is faithfully reproduced in the pattern.

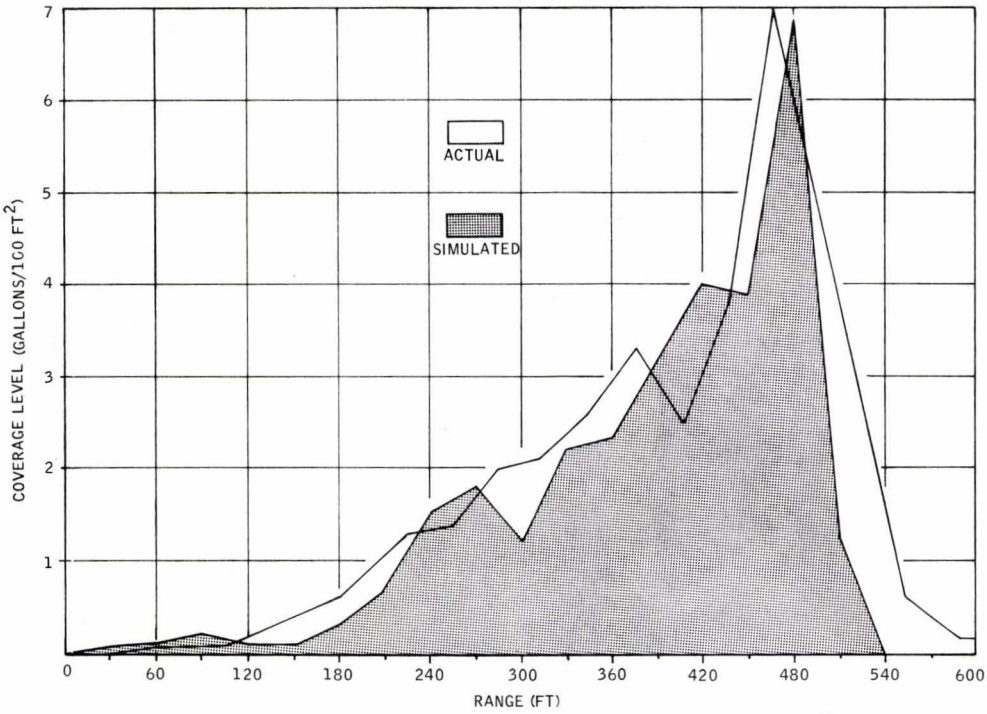


Figure 14. Computer Simulation of CL-215 Drop 4, Flow-Rate 2-14

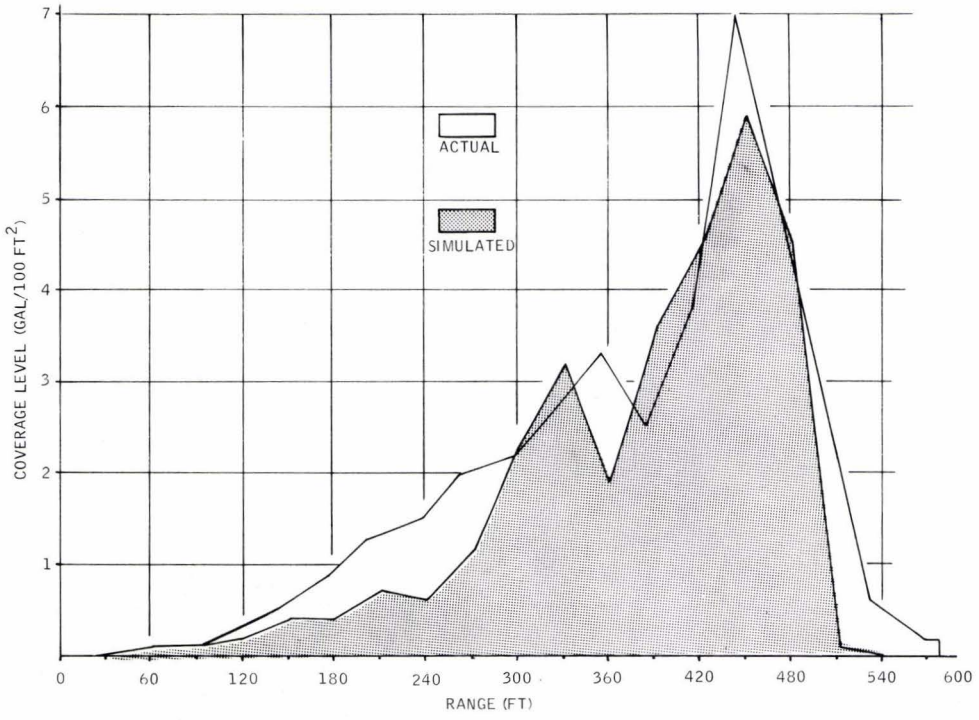


Figure 15. Computer Simulation of CL-215 Drop 4, Flow-Rate 1-14

Table 6. Comparison of Actual and Simulated Patterns

Interval (gal/ 100 sq ft)	Gallons			Area (ft^2)		
	Test	1-14	2-14	Test	1-14	2-14
0.0 - 0.2	99.8	53.9	61.1	142,087	48,600	58,500
0.3 - 1.0	99.0	102.0	99.8	19,688	22,500	19,800
1.1 - 2.0	138.8	119.3	135.1	9,675	8,100	9,900
2.1 - 3.0	88.9	63.2	128.8	3,600	2,700	5,400
3.1 - 4.0	84.1	117.6	98.6	2,475	3,600	2,700
4.1 - 5.0	24.9	117.9	42.1	563	2,700	900
5.1 - 6.0	30.5	53.3		563	900	0
6.1 - 7.0	28.1	0		450		900
7.1 - 8.0	17.2			225		0
8.1 - 9.0						
9.1 - 10.0						
10						
Total	623.8	627.23	626,64	179,437	89,100	98,100

	Test Data	1-14	2-14
Average (1)	2.4	2.6	2.4
Average (2)	.3	.7	.6
Differenced Data:	Mean =	-0.1000332	-0.09206852
(Test-Simulated)	Variance =	0.4653321	0.4055843

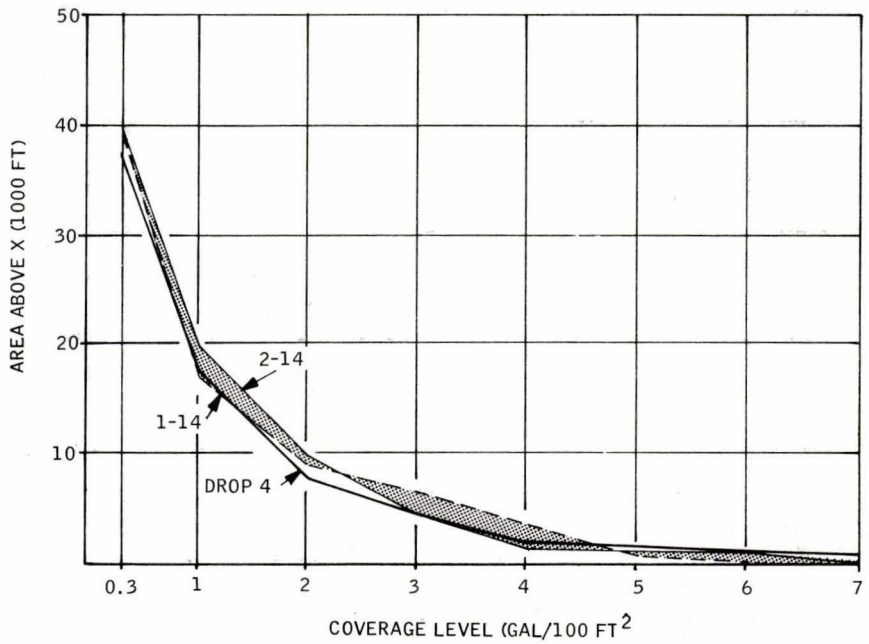


Figure 16. Significant Coverage Areas

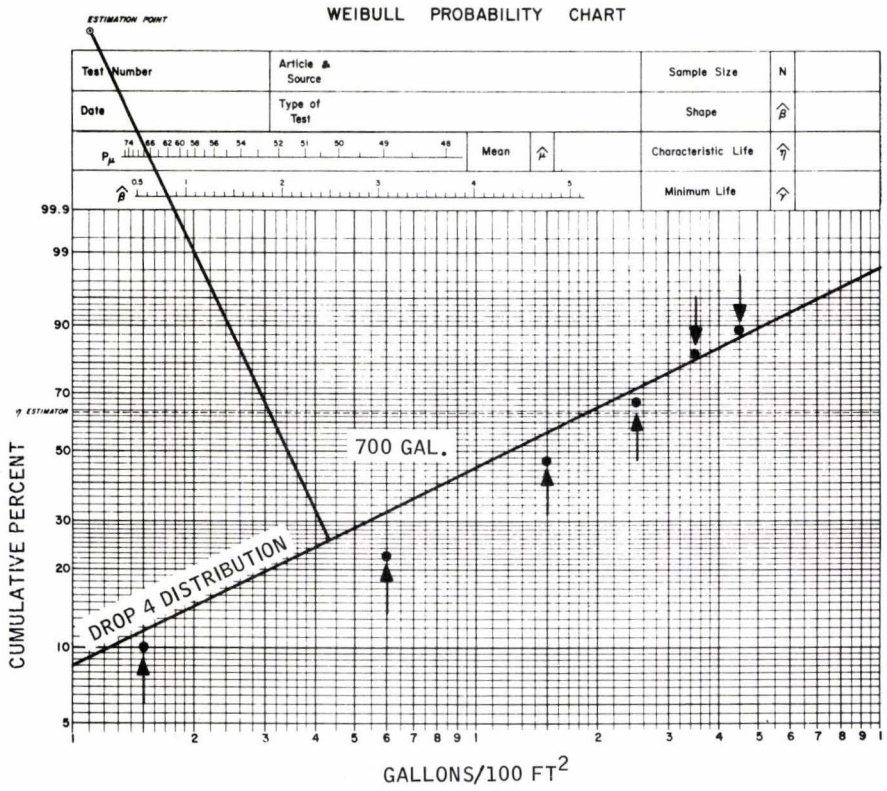


Figure 17. Simulation Data from Actual Flow-Rate (2-14)

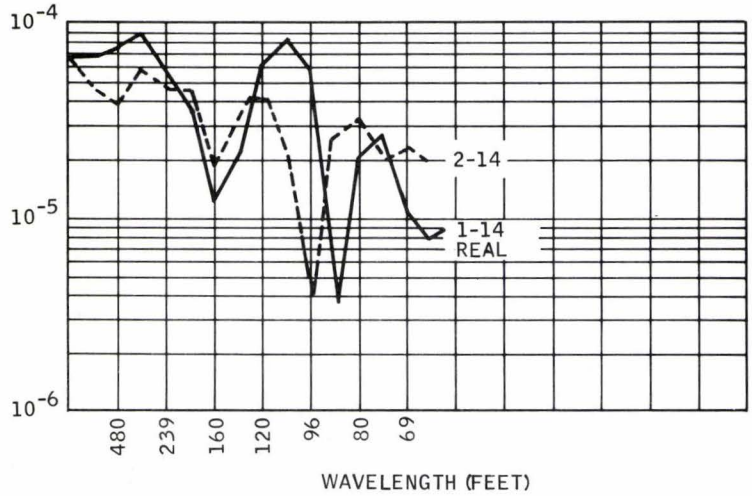


Figure 18. Power Spectra of the Difference Data from Two Simulation Runs

When the simulated pattern is subtracted from the real pattern a new pattern containing the difference data is generated. Reconstructing the range marginal yields a wiggley curve with an average value equal to the variance. If there is regularity (periodicity) in the fluctuations about the variance, it will be revealed in the power spectrum of the figure. These spectra contrast markedly with the spectra generated prior to the actual flow-rate simulation. The levels approach noise; i. e., there is little coherency left. (It was previously thought that these frequency data were relatable to characteristics induced by the breakup process.)

Given the assumption that the pattern is a faithful reproduction of the tank flow-rate, then any frequency component introduced by the simulation could be expected to become visible in the difference data. One regular error of this nature is introduced by the step function flow-rate; i. e., the digital 0. 1-second approximation to a hypothetical smooth flow-rate function suggests that we are periodically over- and under-estimating actual flow at 0. 1-second intervals. If the hypothesis holds, we should be able to identify this phenomenon in the difference data.

The use of a series of square-wave pulses to approximate a straight line is the textbook-analogous case. This yields the cosine transform shown in Figure 19 in which the power spectrum approaches zero at the reciprocal of the pulse repetition rate. Test 1-14 was essentially divided into seven pulses and test 2-14 into six (the initial 0 period is discounted in the program). We would then expect the power spectrum to have values approaching zero at frequencies (lengths) of about 1/7 and 1/6 of the pattern length, respectively, or about 80 and 93 feet. This is almost exactly the case in Figure 18. The approximation of flow-rate has thus introduced an error of the form of Figure 19, which, if removed, could be expected to further reduce the range marginal differences to noise.

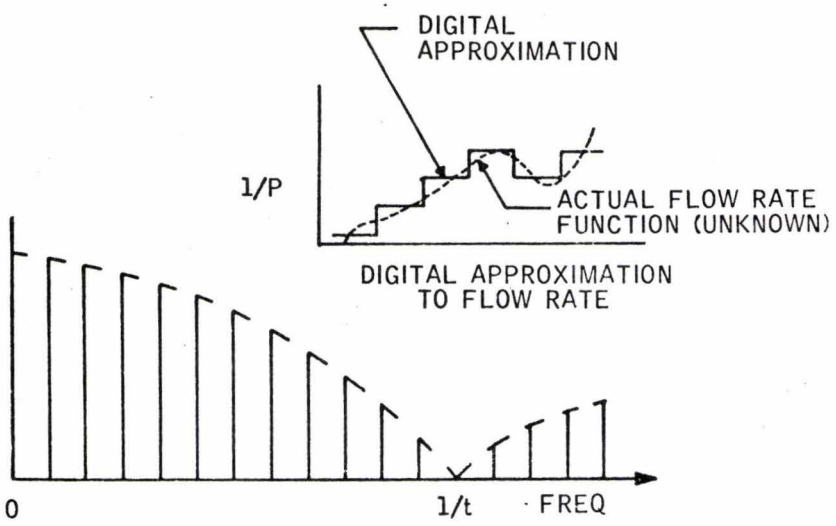


Figure 19. Form of the Power Spectrum of the Difference Between the Function and the Square-Wave Application

Pattern Lengths -- The ability to estimate pattern lengths at various levels was also evaluated. The relationship is directly viewable as an approximation from the pattern cross sections (Figures 14 and 15). Both show a tendency to underestimate length values. Figure 20 shows isoplethic representations of the significant portions of the pattern, which help to explain the apparent bias. In developing the pattern expansion, a symmetry assumption is used. If one grid square is identified at 4 gpc, its counterpart in the other half of the pattern also exists. This tends to produce area distributions that are wider (and shorter) than actually recorded. Correcting this problem could take two forms: (1) Introducing a true center-line row in the simulation (about which the pattern would be symmetrical); this would allow long thin peak areas without automatic doubling. (2) Increasing the number of squares in the grid. Either approach would require reoptimization of the crossrange expansion rules and considerable reprogramming. This is beyond the scope of the current contract. In any case, the simulation appears adequate for length estimates if the bias is recognized.

Figure 21 shows the length estimates with a 30-foot (one-cell) positive bias added. This estimation is analogous to assuming that average

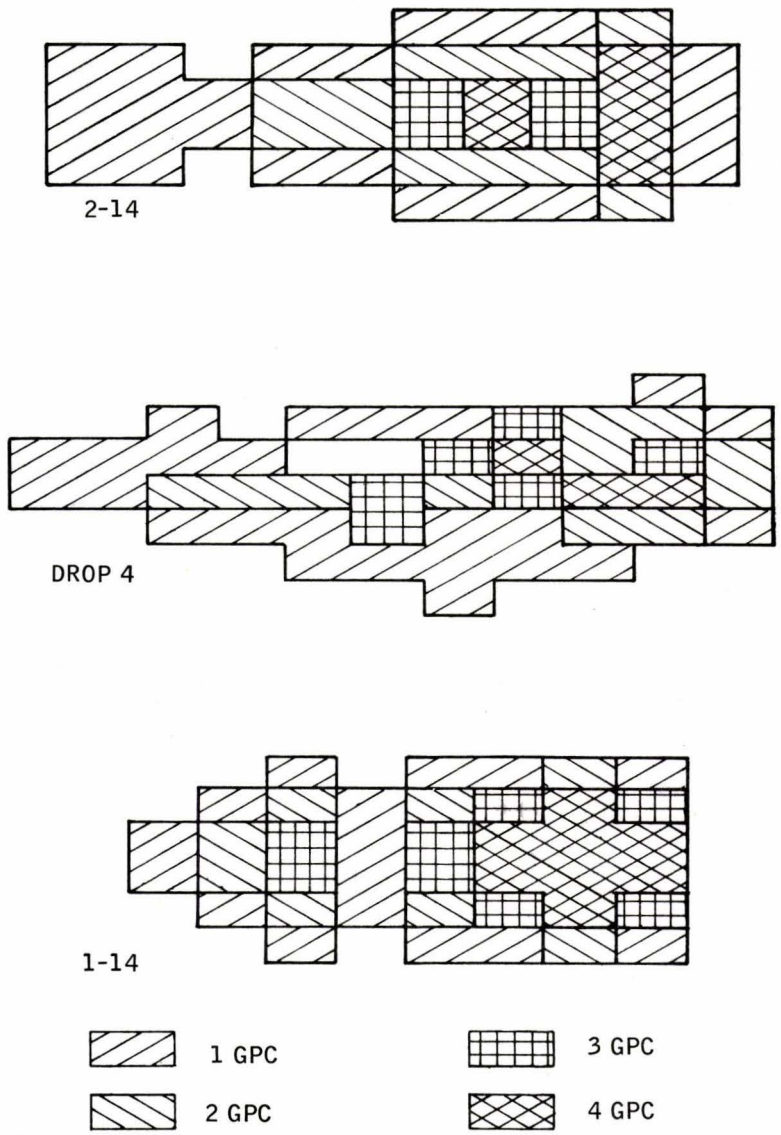


Figure 20. Variations in the Isoplethic Pattern Simulation

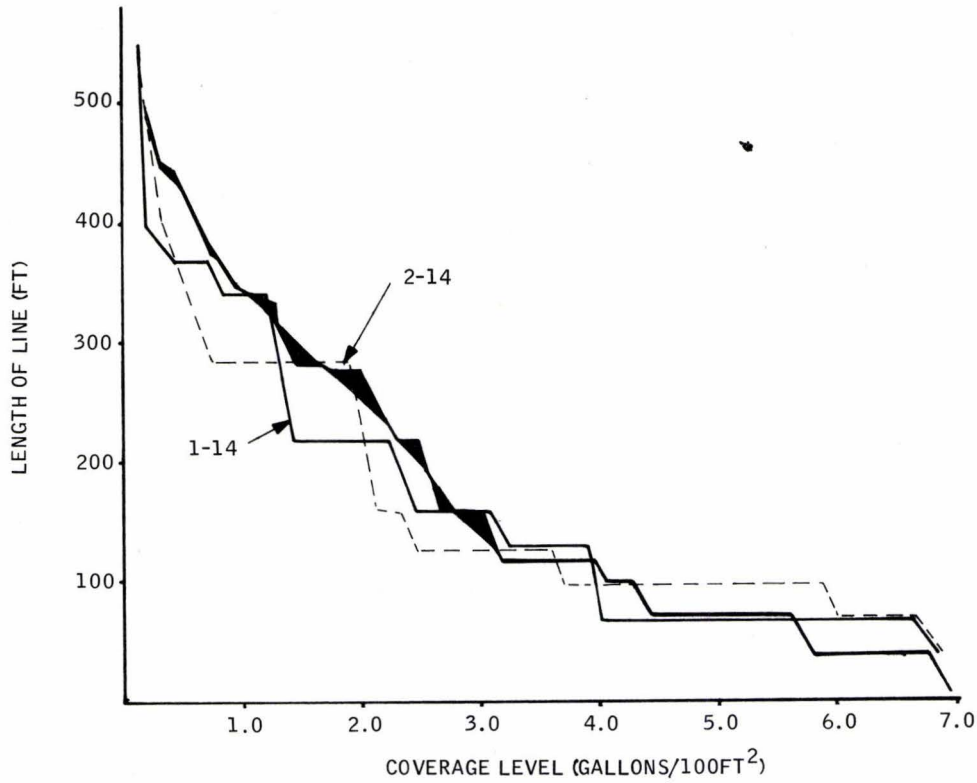


Figure 21. Simulation with +30-foot Bias Compared with Actual

level extends one-half cell beyond the designated area in each direction. It is important to note that the length values are sensitive to the coverage level cutoff value. This is shown both in the pattern cross-section data and Figure 21 where a 0.1-gpc change in the cutoff level can, in certain portions of the pattern, significantly increase or decrease the continuous length.

SECTION IV

TASK II - INCORPORATION OF OTHER RETARDANTS

Task II of the contract required recalibration of the simulation program to predict the performance of retardants other than Phos-Chek XA:

> "Determine the rules for simulating water-like retardants by using MIX 2 and modified RETARD programs with selected drop pattern data and install this capability in the simulation program."

The Honeywell simulation developed under the High-Altitude Retardant Delivery Study was based on the performance characteristics of the gum-thickened retardant, Phos-Chek XA, due to its apparent superiority in providing adequate patterns from higher altitudes. For introducing meaningful guidelines, it is necessary to consider other retardants, notably, Fire-Trol 100, Fire-Trol LC, and water itself. Prior analysis had suggested that these retardants could be treated as a class, behaving similarly in their release from the aircraft, subsequent breakup, and fall to the ground.

RESULTS AND CONCLUSIONS

The CL-215 series of drops using water and Fire-Trol 100 were selected for use in the program development process, so that the basic data were similar to those employed in the previous development of simulation rules for gum-thickened retardants. The selection was also based on the relatively thorough test data available on the CL-215. The calibration study used, in all cases, experimentally derived flow data from the CL-215 tank.

The study confirmed that patterns from both water and Fire-Trol 100 retained the basic relationship to flow-rate observed in the performance of Phos-Chek XA. It further showed that the distribution along the flight path was not a primary source of the difference in performance. Specifically, no changes in the program constants affecting the range distribution were required. In fact, the predicted marginal distributions from the computer programs matched the water-like retardants closer than it had the gum-thickened. (This suggests the possibility that the simulation rules for generating the range marginal distribution for gum-thickened retardants might be improved if they were re-examined using the actual flow-rate data.)

A considerable difference was, however, found in the simulation rules governing crossrange expansion. Even after introducing a different percent recovery curve, the two descriptors of pattern width, σ and semi-crossrange, showed a far higher rate of change with respect to drop height than for gum-thickened retardant. The most significant difference is in the values of σ and percent recovery. These were subsequently incorporated into the program.

It was concluded that retardants other than Phos-Chek XA can be adequately modeled by the revised simulation. The most significant difference from a statistical standpoint is in the rate of pattern spread and the percent recovery. Subsequent work by Shock Hydrodynamics (Ref. 9) has suggested physical bases for this difference in the rheology of the retardants. Attempts to relate these factors to the empirical rules of the program should be considered in further refinements of the simulation.

PRELIMINARY ANALYSIS OF WATER/FIRE-TROL 100 PATTERNS

A set of 3-D pattern plots (Figure 22) was developed for four water drops from the CL-215. This type of plot has been shown useful in visualizing the patterns prior to more detailed analysis. They are shown opposite similar patterns for Phos-Chek XA in Figure 23 for reference. Next, pattern central cross sections were plotted (Figure 24). (These are statistically a form of conditional range distribution that has been found to be a good measure of pattern formation values downrange.) Of the four drops, one from 500 feet appears to violate the basic contention that the pattern replicates flow-rate. Similar anomalous performance was noted for the Phos-Chek drop from 700 feet. Indeed, in subsequent calibration runs, this drop could not be fit into the set by direct relationships. This left us with a very sparse set of drop data for calibration. Consequently, although we had intended to calibrate on water drops using Fire-Trol 100 only as a check value, the five single-tank drops of Fire-Trol 100 were added to the calibration data set. These exhibited the pattern cross sections shown in Figure 25. Once again, one drop of the set (763 feet) exhibited anomalous behavior. Furthermore, the distribution was closely related to that shown in the 500-foot water drop. This suggests the existence of a different mode of tank evacuation. To check this contention, the 700-foot Phos-Chek drop was re-examined. It did not clearly show similarity to the other anomalies, and part of the pattern was not captured on the grid. In a total of 14 drops, a relatively repeatable tank flow-rate was in evidence in at least 12. In two cases there is evidence of a common alternate tank flow, and in a third case the results are inconclusive.

The observation of these anomalies supports the contention that tank performance is more repeatable (less random) than we had previously supposed. For purposes of model development, the anomalous patterns were subsequently ignored.

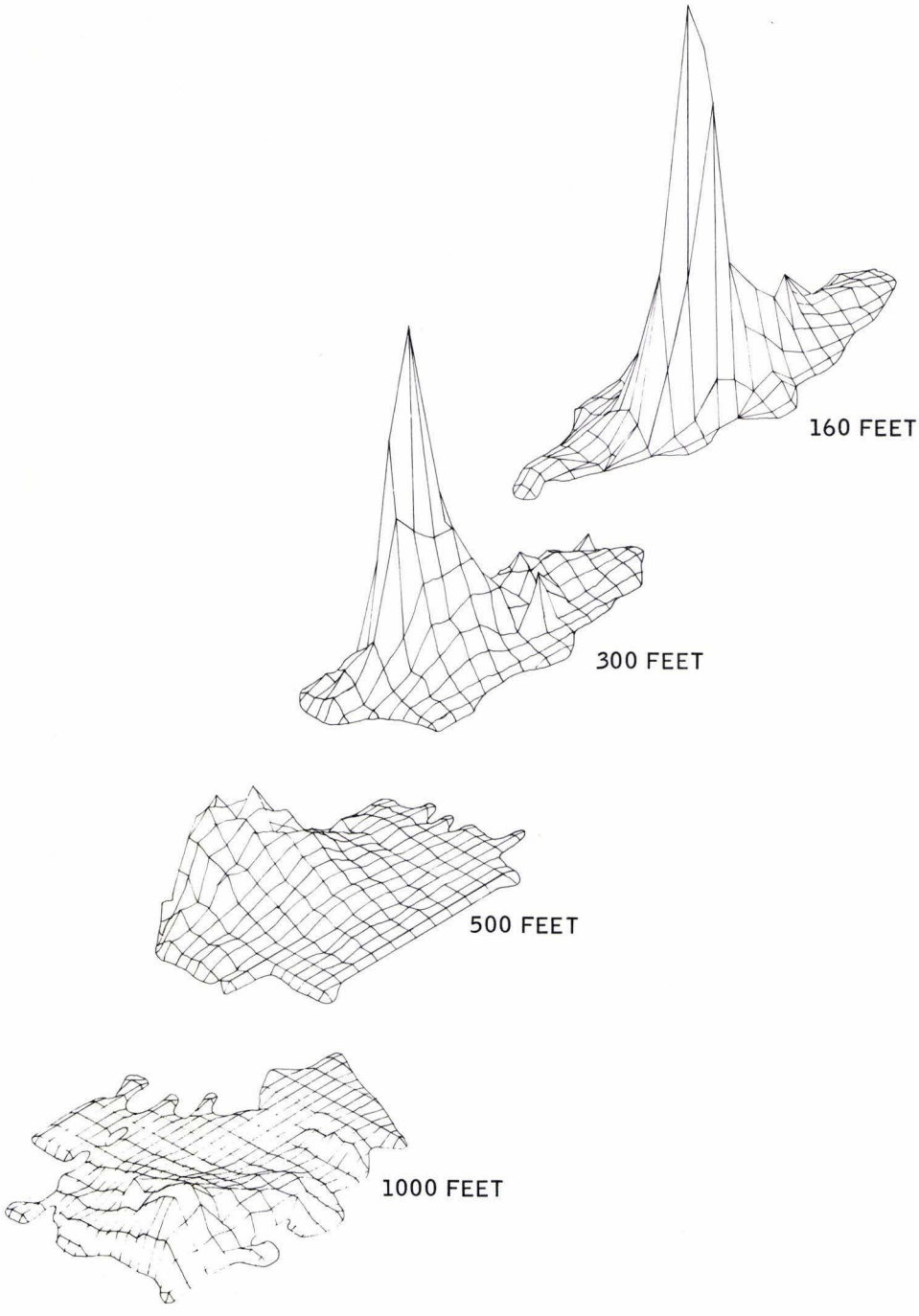


Figure 22. Three-Dimensional Plots of Water Patterns for Four Drop Heights

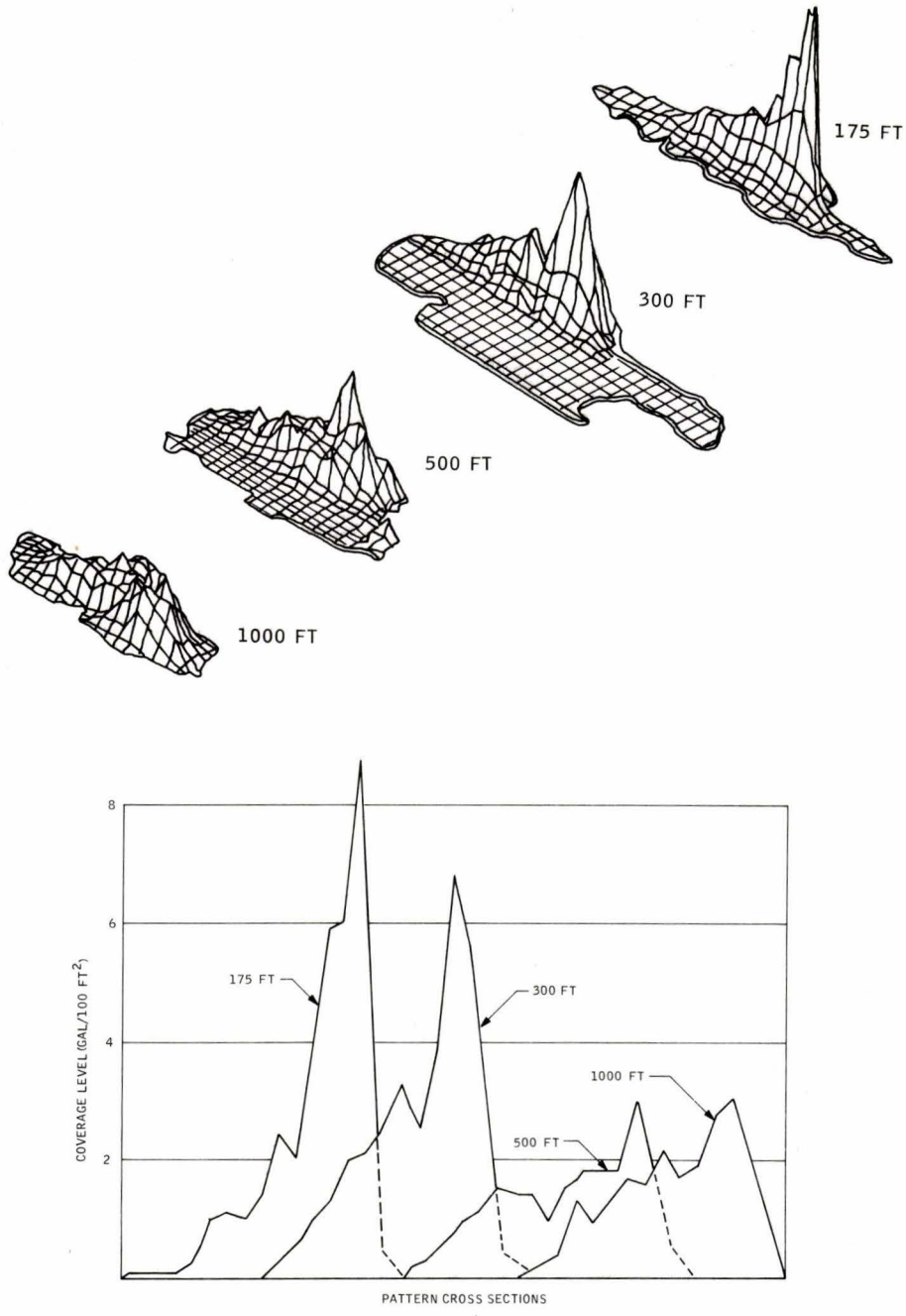


Figure 23. Pattern Change with Altitude for Phos-Chek XA

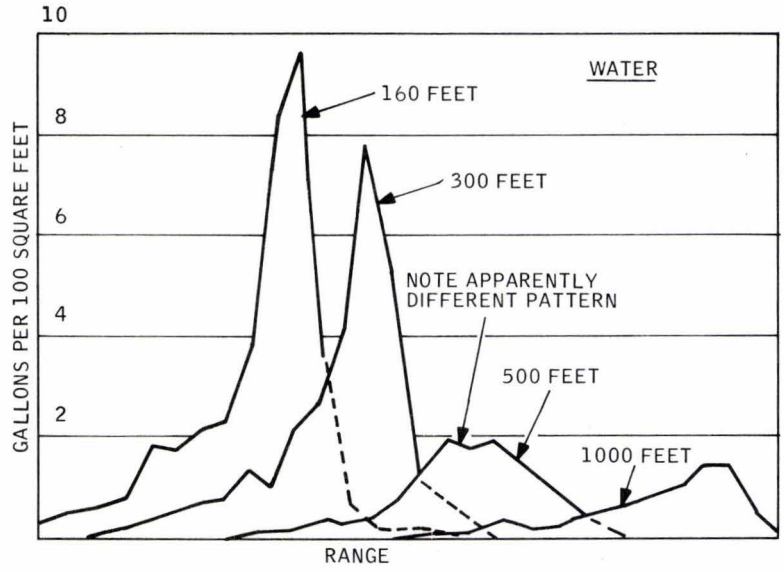


Figure 24. Water Pattern Cross Sections

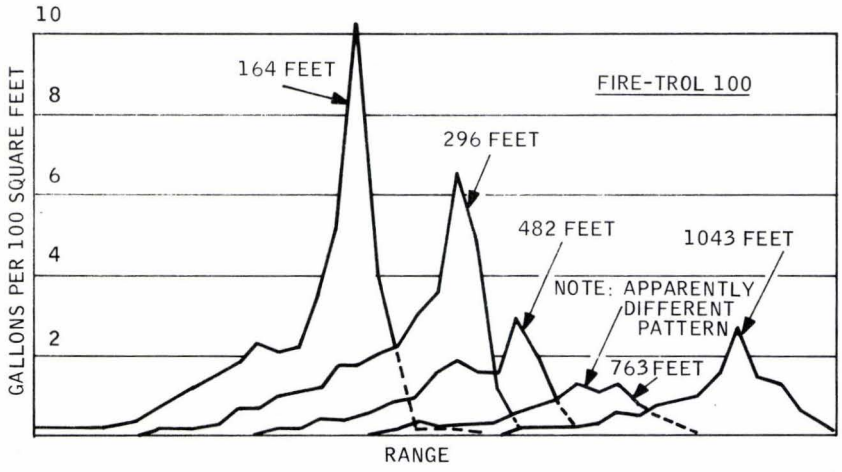


Figure 25. Fire-Trol 100 Pattern Cross Sections

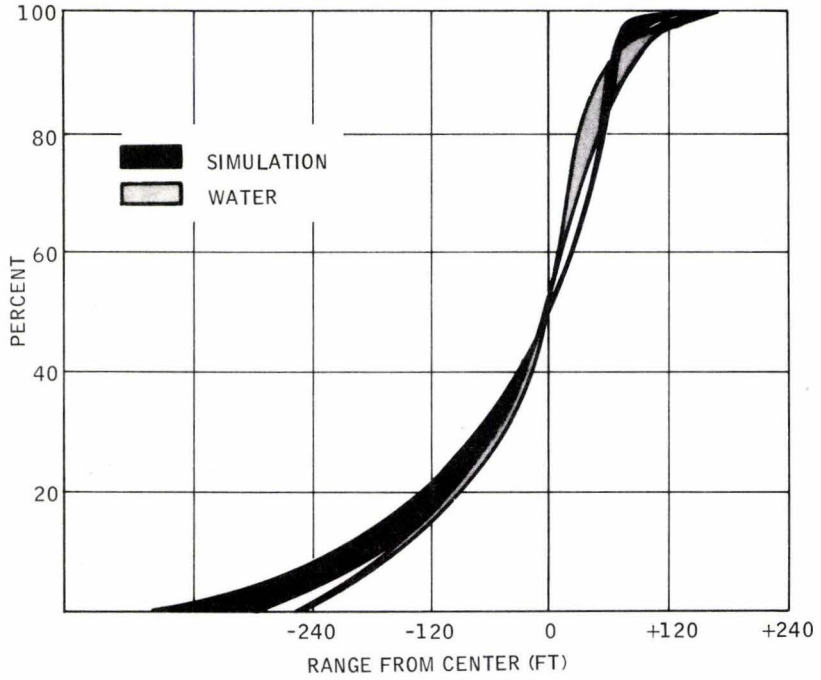
An initial set of runs was made using the MIX 2 program with RETARD to assess the ability of the program rules governing Phos-Chek XA to simulate the pattern generated with water and Fire-Trol 100. The most important finding was that the marginal distributions generated downrange were better simulated for the water-like retardants than for Phos-Chek XA (Figure 26). This meant that the rules difference (other than percent recovery, an empirical formula) must be found in the crossrange subroutines of the program. The possibility that a better range distribution might be achieved for gum-thickened retardant was not investigated since prior effort had shown the adequacy of the simulation for Phos-Chek. This potential for improving predictive accuracy should be investigated in future effort.

Table 7 shows statistics of the pattern for the simulation using Phos-Chek Rules as compared with the "best-fit" for the calibration set.

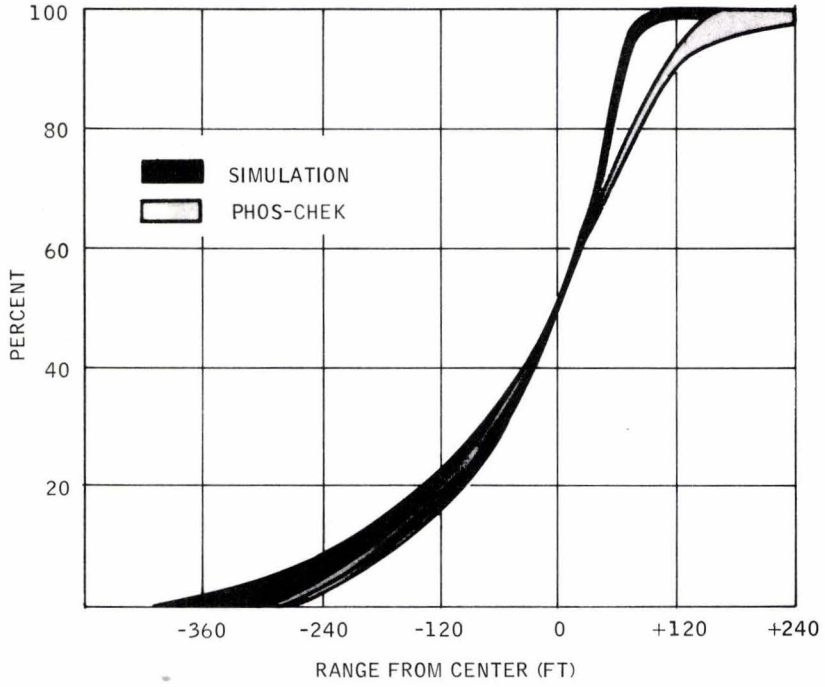
Table 7. Best-Fit Parameters for Other Retardants

Drop Height (ft)	Phos-Chek XA			Other Retardants			Drop No.	Retardant	Actual Drop Height (ft)
	λ (%)	σ (ft)	Semi C-R (feet)	λ (%)	σ (ft)	Semi C-R (feet)			
150	.15	17	65	.15	17	65	10	Water	166
300	.15	24	105	.15	22	90	20	Water	285
500	.18	27	100	.18	40	135	28	FT 100	482
700	(.19)	(30)	(100)			No Data			
1000	.20	32	105	.20	45	135	44	Water	1091

(Estimated)



(a) Simulated and Actual Marginal Distributions for Water Drops, CL-215



(b) Simulated and Actual Marginal Distributions for Phos-Chek XA Drops, CL-215

Figure 26. Comparison of Real and Simulated Pattern Distributions for Two Retardant Types

From Table 7, the following can be noted:

- Fraction in Uniform Distribution, λ – The fraction, λ did not change in the conversion from Phos-Chek to other retardants. Consequently the same rule for developing this fraction was retained in the simulation. The pattern is neither very sensitive to this value nor does it affect substantially the meaningful coverage levels.

- Semi-Crossrange – Semi-crossrange values did appear to change with the retardant type as shown in Figure 27. Comparing the rules for the two retardants suggests that, given the additional data on water and Fire-Trol 100, the Phos-Chek rule might well be revised. It was not done, however, since performance with Phos-Chek appears to be well established, and the parameter simply gives the pattern its look-alike characteristics. (It has little effect on significant coverage levels.)

- Normal Crossrange, σ – The new computer rule for the normal part of the crossrange development routine is shown in Figure 28. Like semi-crossrange, the values are strictly empirical. This parameter does have a significant effect on the meaningful portions of the pattern. Although the Phos-Chek curve could be recalculated, in this case the difference appears minimal.

We would like ultimately to determine a physical basis for these rules. When the data are plotted on a more easily visualized scale (Figure 29) some of the values differentiating between retardants can be evaluated. The physical values of these parameters are pattern-width values. It would appear that initial development of width occurs at about the same rate. This appears commensurate with values shown by Anderson (Ref. 9) in which initial lateral velocities and radius at breakup differ by a small amount between Phos-Chek and water. The zero-crossing

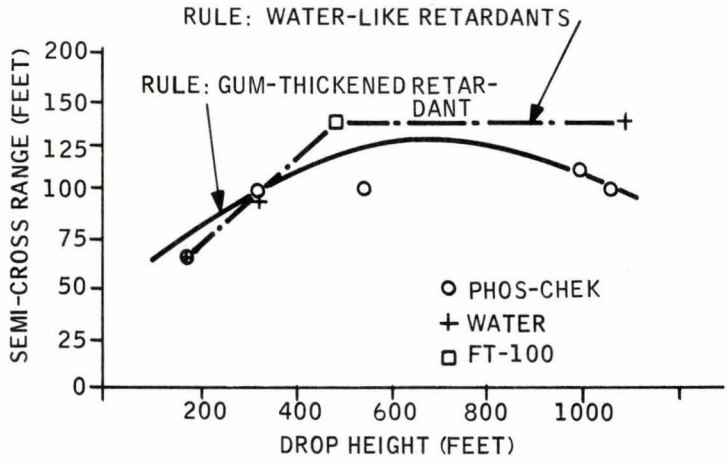


Figure 27. Comparison of Semi-Crossrange Values for Gum-Thickened and Water-Like Retardants

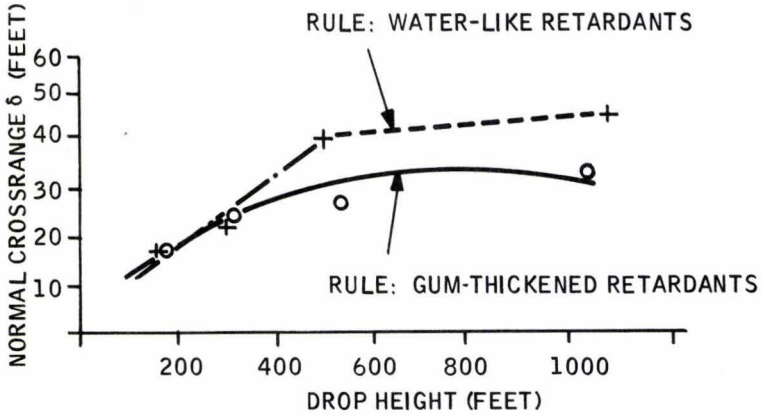


Figure 28. Comparison of Normal Crossrange Rules for Gum-Thickened and Water-Like Retardants

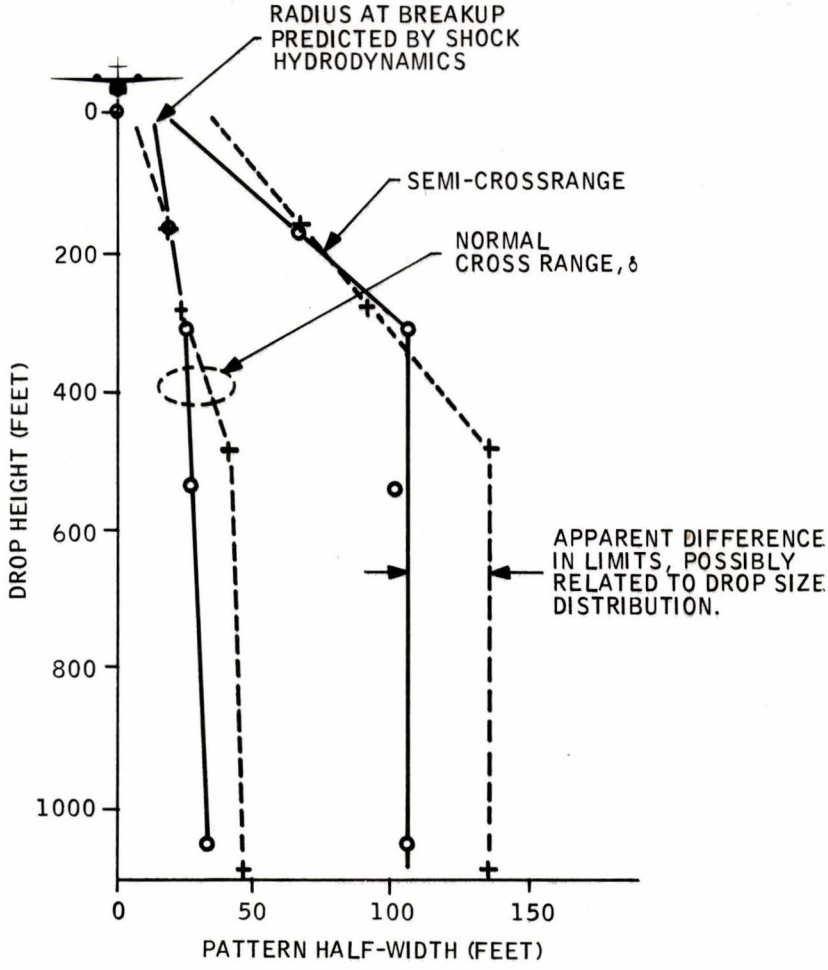


Figure 29. Some Physical Relationships in the Computer Rules

point of pattern half-width would presumably correspond to the radius at breakup, about 12 feet. None of the explored characteristics of retardant breakup clearly account for the apparent difference in cutoff values between Phos-Chek XA and water-like retardants. It may be that this value could be related to the wind drift effects on smaller particles --however, these values reflect only the surviving drops, which are likely to be the larger drops originating from breakup.

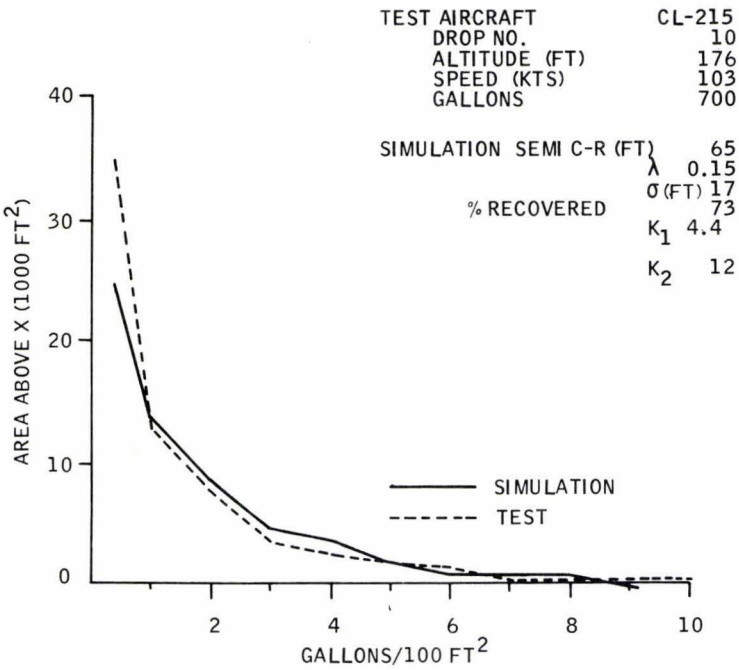
The σ values suggest a crossover point below which water-like retardants generate narrower patterns. This may be a strictly artificial condition since the very sparse data set allows fairly arbitrary interpretation. It does, however, follow the general form of the correlation of pattern width (2 gpc) with effective viscosity conducted by Anderson (Ref. 9) on TBM drops at 100 and 250 feet.

In the final stages of contract effort, additional information became available. In generating guides on the Intermountain B-17 for which considerable comparative data on retardant types are available, the Northern Forest Fire Laboratory noted that performance differences in field tests were not shown in the simulated data. This discovery suggests that the rules differences at low altitude should be re-evaluated. Since the rules for Phos-Chek and water-like retardants were generated independently, under different contracts, a re-evaluation based on Intermountain B-17 data should be considered to improve the program's capability to display real differences in performance.

Although the physical basis for pattern crossrange development remains unclear, some of the basic values can be identified.

PATTERN MATCH DATA

Pattern match data for the selected calibration runs are presented in Figures 30 through 33. In subsequent runs, the remaining three drops using Fire-Trol 100 were used as checkpoints on the computer rules. These matches were considered reasonable. They are shown in Figures 35 through 36.

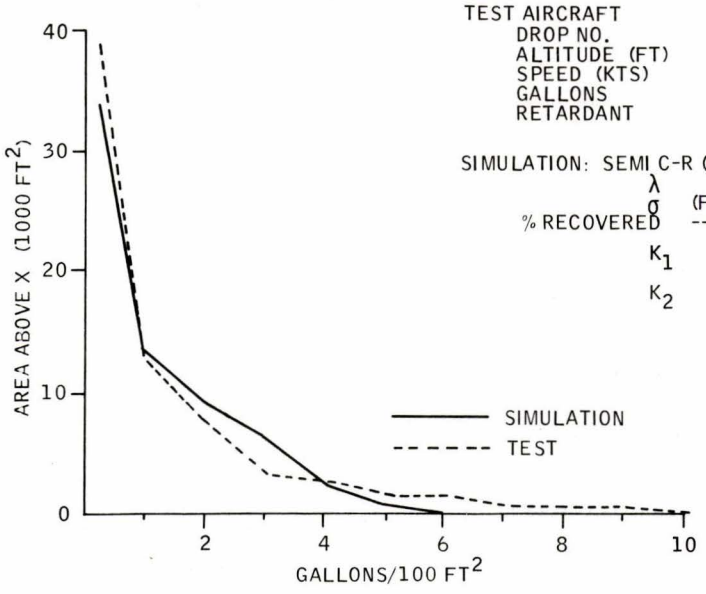


INTERVAL (GAL/100 FT^2)	GALLONS		AREA (FT^2)	
	TEST	SIMULATION	TEST	SIMULATION
0 - 0.2	28.8	19.3	29,362	24,300
0.3 - 1.0	103.0	90.7	22,275	20,700
1.1 - 2.0	82.7	71.5	5,737	5,400
2.1 - 3.0	103.0	92.3	4,162	3,600
3.1 - 4.0	28.6	34.3	788	900
4.1 - 5.0	20.6	81.8	450	1,800
5.1 - 6.0	31.1	49.2	563	900
6.1 - 7.0	29.2	0	450	0
7.1 - 8.0	8.1	0	113	0
8.1 - 9.0	19.6	75.5	225	900
9.1 -10.0	11.1	0	113	0
10	44.7	0	338	0
TOTAL	510.76	514.63	64,575	58,500

	TEST DATA	TEST SIMULATION
AVERAGE (1)	3.5	3.5
AVERAGE (2)	0.8	0.9

DIFFERENCE DATA: MEAN = 0.029856
VARIANCE = 1.019197
(TEST-SIMULATED)

Figure 30. Pattern-Match Data – Drop 10, Phos-Chek XA



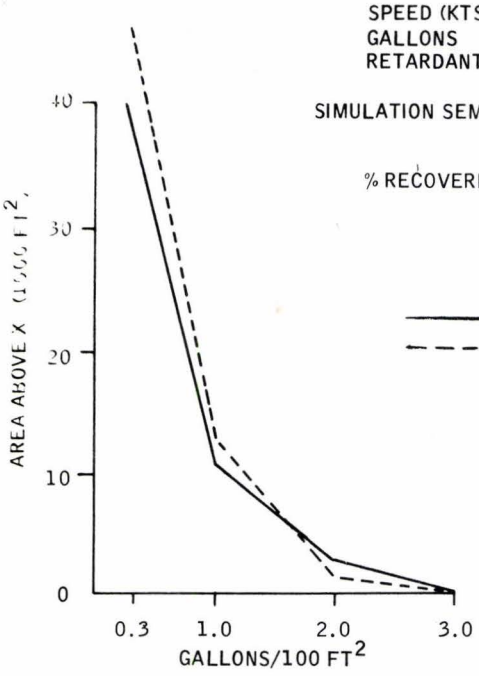
INTERVAL (GAL/100 FT^2)	GALLONS		AREA (FT^2)	
	TEST	SIMULATION	TEST	SIMULATION
0 - 0.2	21.3	32.0	20,812	26,100
0.3 - 1.0	126.0	92.2	25,200	19,800
1.1 - 2.0	89.7	66.0	6,075	4,500
2.1 - 3.0	94.1	161.1	3,712	2,700
3.1 - 4.0	30.2	119.1	900	3,600
4.1 - 5.0	35.1	86.4	788	1,800
5.1 - 6.0	18.6	52.7	388	900
6.1 - 7.0	56.2	0	900	0
7.1 - 8.0	16.4	0	225	0
8.1 - 9.0	9.4	0	113	0
9.1 - 10	10.6	0	113	0
TOTAL	507,7	509,5	59,175	59,400

	TEST DATA	SIMULATION DATA
AVERAGE (1)	2.9	2.8
AVERAGE (2)	0.8	0.9

DIFFERENCE DATA: MEAN = 0.0184
VARIANCE = 0.547
(TEST-SIMULATED)

Figure 31. Pattern-Match Data - Drop 20, Phos-Chek XA

TEST AIRCRAFT	CL-215
DROP NO.	28
ALTITUDE (FT)	482
SPEED (KTS)	102
GALLONS	700
RETARDANT	FIRE-TROL 100
SIMULATION SEMI C-R (FT)	135
λ	0.18
σ (FT)	40
% RECOVERED	55.4
K_1	4.4
K_2	12



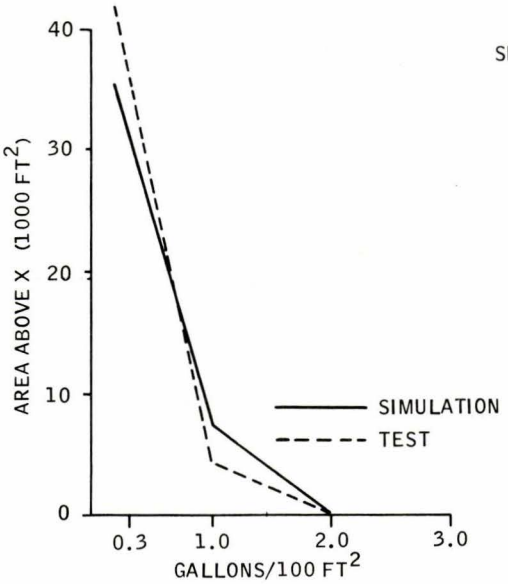
INTERVAL (GAL/100 FT^2)	GALLONS		AREA (FT^2)	
	TEST	SIMULATION	TEST	SIMULATION
0.0 - 0.2	28.7	61.8	31,162	88,200
0.3 - 1.0	161.1	141.0	33,637	27,900
1.1 - 2.0	169.1	121.3	11,700	8,100
2.1 - 3.0	29.1	66.7	1,237	2,700
TOTAL	388.08	390.96	77,737	126,900

	TEST DATA	SIMULATION DATA
AVERAGE (1)	1.1	1.1
AVERAGE (2)	0.5	0.3

DIFFERENCE DATA: MEAN = 0.014470
VARIANCE = 0.117062
(TEST-SIMULATED)

Figure 32. Pattern-Match Data – Drop 28, Phos-Chek XA

TEST AIRCRAFT	CL-215
DROP NO.	44
ALTITUDE (FT)	1000
SPEED (KTS)	110
GALLONS	700
SIMULATION SEMI C-R (FT)	135
λ	0.2
σ (FT)	45
% RECOVERED	41.3
K_1	4.4
K_2	12

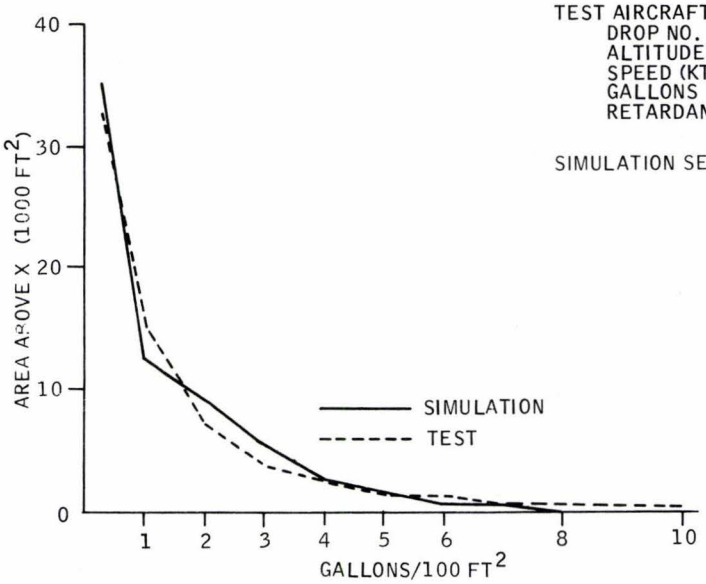


INTERVAL (GAL/100 FT^2)	GALLONS		AREA (FT^2)	
	TEST	SIMULATION	TEST	SIMULATION
0 - 0.2	63.0	65.4	70,000	118,800
0.03 - 1.0	173.4	130.3	37,462	27,900
1.1 - 2.0	52.8	96.1	4,275	7,200
TOTAL	289.2	291.8	112,050	153,900

	TEST DATA	SIMULATION DATA
AVERAGE (1)	0.7	0.8
AVERAGE (2)	0.3	0.2

DIFFERENCE DATA: MEAN = 0.029465
VARIANCE = 0.032846
(TEST-SIMULATED

Figure 33. Pattern-Match Data - Drop 44, Phos-Chek XA



TEST AIRCRAFT CL-215
DROP NO. 19
ALTITUDE (FT) 164
SPEED (KTS) 106
GALLONS 700
RETARDANT FIRE-TROL 100

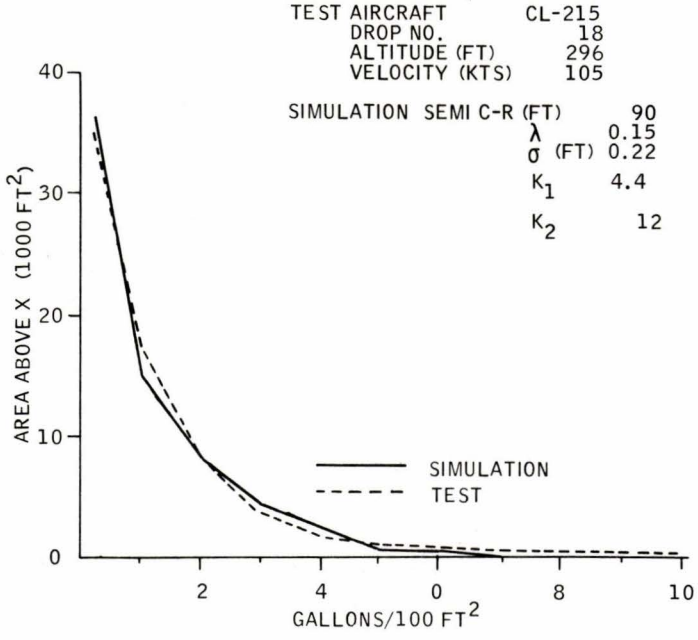
SIMULATION SEMI C-R (FT) 65
λ 0.15
σ (FT) 17
K_1 4.4
K_2 12

INTERVAL (GAL/100 FT²)	GALLONS		AREA (FT²)	
	TEST	SIMULATION	TEST	SIMULATION
0 - 0.2	30.0	18.6	39,375	23,400
0.3 - 1.0	86.4	101.2	17,550	22,500
1.1 - 2.0	113.0	56.4	7,875	3,600
2.1 - 3.0	80.0	85.0	3,375	3,600
3.1 - 4.0	47.2	102.9	1,350	2,700
4.1 - 5.0	40.6	42.1	900	900
5.1 - 6.0	18.0	48.6	338	900
6.1 - 7.0	43.4	0	675	0
7.1 - 8.0	16.0	65.5	225	900
8.1 - 9.0	9.2	0	113	0
9.1 - 10	0	0	0	0
> 10	32	0	225	0
TOTAL	516.27	520	72,000	58,500

	TEST DATA	SIMULATION DATA
AVERAGE (1)	3.3	3.2
AVERAGE (2)	0.7	0.9
% RECOVERED	73.5	74.3

DIFFERENCE DATA: MEAN = 0.040778
VARIANCE = 0.659823
(TEST-SIMULATED)

Figure 34. Pattern-Match Data – Drop 19, Fire-Trol 100

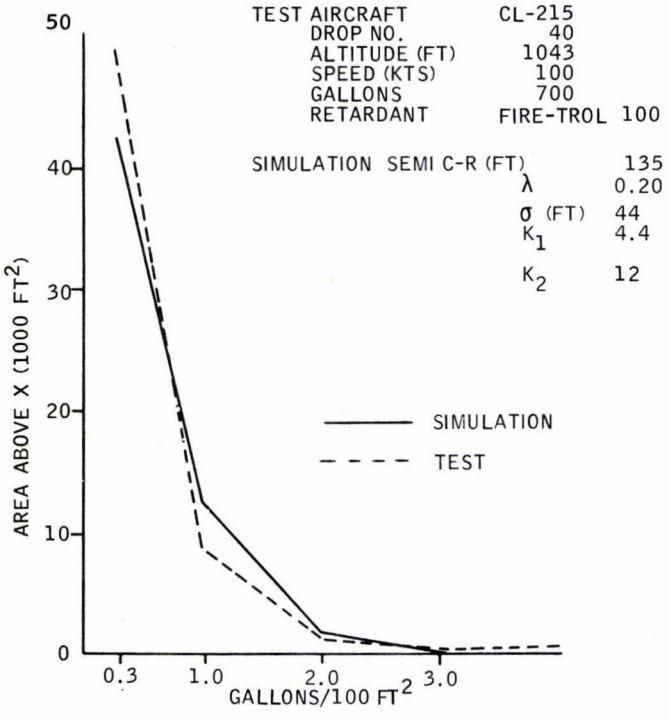


INTERVAL (GAL/100 FT^2)	GALLONS		AREA (FT^2)	
	TEST	SIMULATION	TEST	SIMULATION
0 - 0.2	27.9	41.4	36,450	34,200
0.3 - 1.0	95.6	95.5	18,000	20,700
1.1 - 2.0	137.6	112.0	9,337	7,200
2.1 - 3.0	94.6	94.2	3,938	3,600
3.1 - 4.0	74.7	63.5	2,137	1,800
4.1 - 5.0	34.2	79.9	788	1,800
5.1 - 6.0	30.5	0	563	0
6.1 - 7.0	21.1	60.6	338	900
7.1 - 8.0	8.6	0	113	0
8.1 - 9.0	0	0	0	0
9.1 - 10.0	0	0	0	0
> - 10	18.7	0	113	0
TOTAL	544.21	547.07	71,775	70,200

	TEST DATA	SIMULATION DATA
AVERAGE (1)	2.7	2.6
AVERAGE (2)	.7	.8
% RECOVERED	77.74	78.1

DIFFERENCE DATA: MEAN = 0.027528
VARIANCE = 0.336478
(TEST-SIMULATED)

Figure 35. Pattern-Match Data – Drop 18, Fire-Trol 100



INTERVAL (GAL/100 FT^2)	GALLONS		AREA (FT^2)	
	TEST	SIMULATION	TEST	SIMULATION
0 - 0.2	55.3	59.8	53,775	87,300
0.3 - 1.0	189.9	145.0	41,737	29,700
1.1 - 2.0	96.8	151.5	7,537	10,800
2.0 - 3.0	28.0	37.9	1,125	1,800
3.1 - 4.0	0	0	0	0
4.1 - 5.0	4.9	0	113	0
TOTAL	374.94	394.3	104,287	129,600

	TEST DATA	SIMULATION DATA
AVERAGE (1)	1.0	1.1
AVERAGE (2)	0.3	0.3
% RECOVERED	53.6	56.3

DIFFERENCE DATA: MEAN = 0.0316737

VARIANCE = 0.1822286
(TEST-SIMULATED)

Figure 36. Pattern-Match Data - Drop 40, Fire-Trol 100

SECTION V
TASK III - IMPROVE PROGRAM OPERATION

Task III of the contract required revisions to the simulation program PATSIM to simplify operation:

> "Revise the Improved Simplified Program (PATSIM) to provide: (a) simplified input, (b) extension of documentation instructions, and (c) incorporation of the capabilities of Task II."

The Program PATSIM was introduced at the end of Contract 26-2888 to provide a simplified simulation run with readily evaluated output. The program was complicated by a relatively large number of run options and input conditions. In addition, changes were introduced during this contract, adding to the complexity. We have retained all of the operational modes but considerably reduced the number of inputs that are required.

RESULTS AND CONCLUSIONS

The program PATSIM was revised to allow operation from measured flow-rate data using only five additional input values: (1) selection of retardant type (gum-thickened or water-like), (2) specification of the number of gallons in a tank, (3) the number of tanks released at one time, (4) aircraft velocity, and (5) drop height. This is believed to be the most useful and direct mode of operation in which measured flow-rate data is the only test value required. A set of runs can then be generated for various retardants, tank combinations, and deliveries. Run time in this mode requires about 8.5 seconds of compilation time plus about one system second per run. Thus a performance matrix of

62 tests such as performed on the CL-215 (Phos-Chek, Fire-Trol 100 and water -- excluding two tank trails) can be run using approximately 70 seconds of system time on the CDC 6600.

An additional subroutine, PATADD, was also introduced in the program. This subroutine uses an algorithm developed by Max Conner (NFFL) to estimate the maximum line lengths and delay between tank releases for multiple-tank trail drops. It is an optional subroutine that adds about 9 seconds to the run time for each operation. It does, however, provide estimates of tank sequencing time that would require a large number of test flights to generate if the same issues were to be determined experimentally.

It was concluded that the PATSIM program, running with experimentally determined flow-rate data, is capable of predicting pattern performance with sufficient accuracy to serve mission-planning and analysis functions, such as the generation of User Guidelines. Other run options incorporate use of door-opening data or the theoretical prediction of tank flow-rates from door-opening rates and tank geometry. Although these run options have been retained, the addition of door-opening data (which changes the downward ejection velocity of the fluid) does not significantly affect pattern results. The theoretical flow-rate prediction based on Bernoulli steady-state equations appears not to reflect actual flow-rates and must be considered suspect as any but a gross estimator of performance.

PROGRAM DOCUMENTATION

Appendix A contains the revised and updated program. A complete listing, duplicate card deck, and example run have been furnished to the Northern Forest Fire Laboratory.

PATADD SUBROUTINE

One task of the initial proposal was to introduce a statistically reasonable method of handling multiple-tank drops. This task was not, however, written into the contract in final negotiations. During the course of the program, the need for some technique of handling this tactical option became increasingly apparent. Specifically, some aircraft such as the Gilbertson DC6B and Hemet Valley S2F with marginal single-tank patterns actually appear to provide considerable performance efficiency when the single-tank drops are properly strung together. Consequently, Honeywell initiated a limited effort to develop some estimator of this performance.

There are two basic ways to view the tank sequencing problem: (1) to synthesize composite flow-rates based on tank sequences along the flight path -- this views multiple-tank release as if it were a highly variable flow-rate from a single, larger tank; (2) to add patterns after they are developed on the ground.

Both techniques were briefly explored using a double-tank drop from the CL-215. Measured test data suggested that in the drop, supposed simultaneous delivery was actually a two-tank release with a small systematic delay. Therefore, patterns were run with the composite flow-rate generated by the delay in a routine that allowed adding single-tank patterns with one-, two-, or three-cell overlaps, and one-, two-, or three-cell offsets. By far the best match was achieved with the second technique. The best match from a statistical sense was achieved with the second pattern shifted 60 feet downrange and offset 15 feet in crossrange. Central cross sections for the actual drop (21) and the simulation are compared in Figure 37.

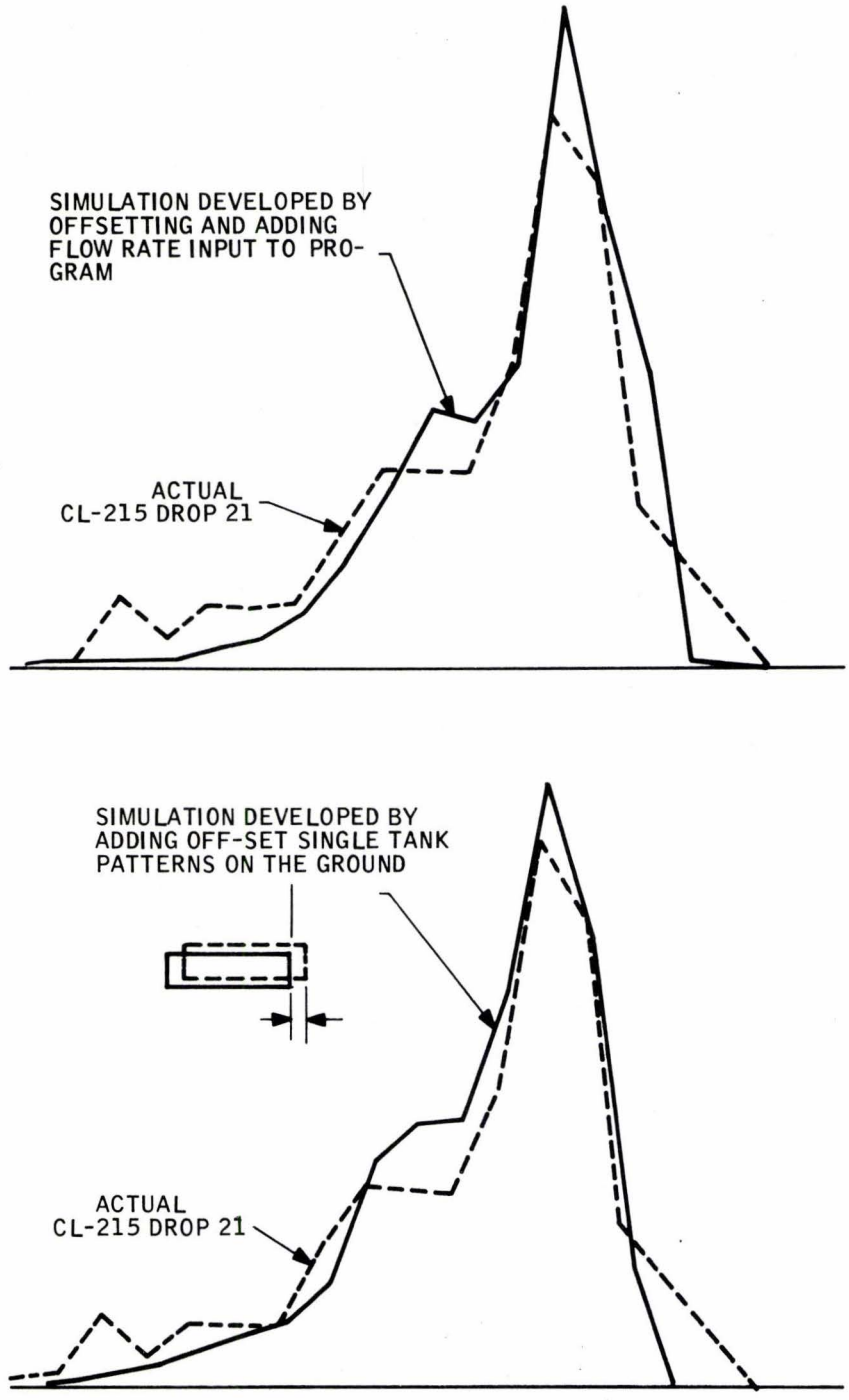

SIMULATION DEVELOPED BY OFFSETTING AND ADDING FLOW RATE INPUT TO PRO-GRAM
ACTUAL CL-215 DROP 21
SIMULATION DEVELOPED BY ADDING OFF-SET SINGLE TANK PATTERNS ON THE GROUND
ACTUAL CL-215 DROP 21

Figure 37. Two Methods of Simulating Double-Tank Drops

There are also considerable programming advantages in handling the addition of the drops on the ground; consequently, this approach was selected as the best to yield an approximate technique.

On the above basis a simple algorithm was developed to estimate the additional line that could be achieved by properly sequenced tanks:

$$\text{Pattern length (ft)} = (N - 1) \times (\text{Range 1 gpc Front} - \text{Range G gpc Rear}) + (\text{Range G gpc Front} - \text{Range G gpc Rear})$$

where N - number of patterns employed, G = the coverage level of interest in gallons per 100 ft^2, and ranges are calculated from the simulated pattern of a single drop (Figure 38). This calculates the offset to achieve maximum line at the G coverage level.

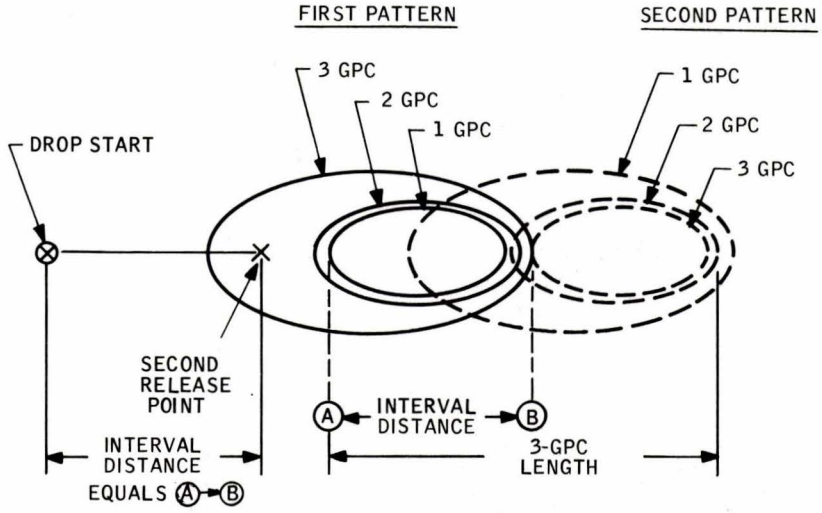


Figure 38. A Method of Estimating Release Interval from Overlapping Patterns on Ground

The appropriate interval setting is then given by

$$\text{Interval (sec)} = \frac{\text{Range 1 gpc Front} - \text{Range G gpc Rear}}{\text{Aircraft Velocity (knots)} \times 1.698}$$

A second algorithm based on the principle of adding ground patterns was developed at the Northern Forest Fire Laboratory by Max Conner. This computer-based program essentially shifts and overlays the simulated pattern until it determines maximum values. It yields a greater precision of the estimated delay and appears to match experimental data better than the Honeywell algorithm. This approach was therefore adopted for use in the PATSIM program.

A program deck furnished by the Northern Forest Fire Laboratory was modified to perform as an add-on subroutine to the PATSIM program. The modifications were minor to enable direct use of the PATSIM-generated patterns. One other change was made to limit the number of patterns explored in the subroutine to the number of tanks available.

This subroutine, PATADD, was included in the simulation as an optional operation. (It does considerably increase the run time to about 10 seconds, but the output data is equivalent to far more than 10 additional runs if the same values were to be determined from iterative tests varying flow-rate.)

FLAWS OF THE BERNOULLI SIMULATION

The simulation of patterns from a flow-rate predicted using the Bernoulli equations was originally adopted from MacPherson. This system allowed the prediction of flow-rates when tank geometry and door opening rates are known. Although we were aware that tank-release phenomena were far from steady-state, the technique had been shown in two of three experimentally verified cases to provide a good estimate of flow rate. Both the Gilbertson DC6B and the P2V had been adequately estimated; the CL-215, however, was not (Ref. 3).

Although the objective of this program was to use measured flow-rate data, not theoretical simulations, some difficulties were encountered in interpreting measured flow data. To assist in resolving these problems, theoretical flow-rates were generated in several instances. These runs did not, however, produce patterns with the same characteristics as those indicative of actual flow-rates. As a result, the theoretical flow-rate simulation must be considered suspect -- the apparent good matches on P2V and DC6B are fortuitious rather than fundamental. The following analysis, though far from exhaustive suggests the reasons.

Two problems of the Bernoulli equations as they are employed in the program can be identified. First, under some conditions of tank geometry and door-opening rate, excessive ejection velocities are predicted. Second, during unrestricted flow, predicted velocity declines despite the fact that the fluid is in free fall. In association the decline in velocity due to head loss in a restricted tank (Aero Union B-17 trail) appears excessive.

Examination of several simulation runs shows that, under certain door-opening and tank geometric conditions, the velocity change at the top of the tank can exceed gravity. This is clearly suspect since the limit velocity buildup at the top of the tank in any given time increment should not exceed the value achieved by the acting acceleration. Thus, flow out the bottom must probably be limited by a limit velocity buildup at the top of the tank.

Secondly, the simulation equations view the only component of velocity at the top of the tank as that instantaneously generated by the efflux velocity, whereas at each computer step after the first there is a discrete (and increasing) initial velocity at the top of the tank.

These flaws are not so much in the basic physics of the Bernoulli simulation but in the way the equations are interpreted for programming application. It should be noted that the simulation on this basis is potentially correctable; i. e., it can be changed without reverting to a more sophisticated simulation viewpoint. It is thus recommended that attempts to correct the simulation include assessment of changes such as the above before reverting to finite element approaches -- i. e., the complex solution to Navier Stokes equations.

In line with the above, serious consideration should also be given to incorporating venting parameters in the flow rate equations. This was brought home in analysis of S2F flow data, where a pressure buildup due to inadequate venting caused the head to stop and tank evacuation to occur from the bottom (see Task IV). A different form of the familiar Bernoulli equation estimates the pressure drop in air due to flow through an orifice. Thus vent area, the area at the top of the tank, W_Z, and the velocity of the top of the fluid surface can be used to calculate the air-pressure drop in the tank and its consequent effects on release velocity. There is sufficient evidence in flows analyzed to data to indicate that even small pressures modify flow-rate and that provisions to account for this should be considered at the same time other changes to the simulation are made.

SECTION VI
TASK IV - DEVELOP USER GUIDELINES

Task IV of the contract required the development of the User Guidelines themselves in terms of data presentation, content, format and methodology, as well as the generation of guides covering four aircraft:

> "Develop User Guidelines based on operation of the improved simulation for the evaluation of four aircraft for which measured flow data are available. Use the results of prior accuracy studies, fuel coverage estimates, and existing techniques to generate nomographs or parametric windows that will allow field personnel to estimate the best mission for various fire situations in which each of the four aircraft may be employed."

Considerable effort was applied to the exploration of techniques to present the material now incorporated in the user guides and their instruction manual. Most of this material is of limited interest and is not repeated here. This effort resulted in the development of pattern footprints and best-strategy charts previously described. This section contains a brief discussion of some of the difficulties encountered in working with measured flow data and the approximations made in carrying through with the guideline material. A full discussion of the method of generating the guidelines appears in Section III.

DEFINITION OF CONTENT

An initial review of proposed guideline material was conducted at the Northern Forest Field Laboratory with field personnel. The results

of this meeting called attention to two major discrepancies in the work that had been conducted previously. First, the concept of appropriate coverage levels, gallons per 100 square feet, though used extensively in evaluating patterns from a test standpoint, was found to be relatively unfamiliar value in the field. Second, the idea of developing maximum pattern area, also a convenient value for analytical purposes, was found to have little practical application in the field.

The first item had the effect of increasing the difficulty of generating useful guidelines, in that it was now necessary to introduce the concept of appropriate coverage levels before the material generated on tank performance could be used. This led rather directly to the proposition of a summary guide or instruction to support the data on specific aircraft and to make available in simplied form the knowledge of aerial firefighting developed over the last several years. The second item simplified the data summarization task by focusing decision data on the practical values of pattern length. Attempts to display area were subsequently abandoned as being of little use. (Area data are still available in the computer output.)

The content of the guidelines was then redefined to include:

- A general document, or manual, treating aerial delivery of retardant as a basic background for the interpretation of data contained in the specific guides.

- Specific guides related to particular aircraft and tanking systems, with emphasis on answering questions regarding tank control options available and how they should be used in terms of desired pattern length and fuel coverage levels.

The guides were subsequently developed within this context.

SELECTION OF SPECIFIC AIRCRAFT

Under terms of the Task Statement any four aircraft for which flow rate data were available would be selected. Basically, it was desired to use aircraft that had already been tested in actual drop evaluation. In this way the conclusions generated by the computer program could be checked and any difficulties encountered corrected.

The first aircraft selected was the CL-215, not so much because of its anticipated usage, but because it had been thoroughly evaluated in actual tests. Computer data paralleling test results were also available, since it had been the calibration aircraft in previous studies. No difficulties were encountered in operating with measured flow data.

The second aircraft selected was the Gilbertson, DC6B. This aircraft was the first for which measured flow data were available and was known to perform approximately in the manner predicted by thr program. It has been used as a check-case aircraft in prior work. Some difficulties were nonetheless encountered in using the measured flow-rate because the measured flow data covered only the first 230 gallons evacuated. This left 120 gallons (about one-third of the flow) unaccounted for. Attempts to synthesize a flow more accurately than a straight extrapolation were conducted (see discussion below), but in general it was decided that the extrapolated value was sufficiently accurate for use, and it was employed in the simulation.

The third aircraft selected was an Aero Union B-17, which was equipped with two choices of door area release. This aircraft was representative of one with presumably superior controllability. It also met the requirement for having been tested, though far less extensively than the other two.

No difficulties were encountered in operation with this aircraft.

The fourth aircraft selected was an S2F of the type being tanked by the California Division of Forestry. There are several tank versions extant. Flow-rate data existed on the aircraft at Hemet Valley, which had also been subjected to actual flight tests. During the course of static testing, some abnormalities in flow due to common and presumably inadequate venting had been noted. It was, nonetheless, assumed that the problem did not extend to a single-tank release (venting adequate) and that independent venting of the tanks could be accomplished. In the course of analysis it was discovered that pressure buildup due to the venting configuration did confound flow data in the single tank, and consequently a synthesized flow-rate was developed as discussed below. This synthesized flow-rate appears to adequately describe the system and suggests techniques of introducing vent pressure into future flow-rate simulations.

FLOW-RATE STUDIES

Gilbertson DC6B

Measured flow-rate data on the DC6B traced the actual flow-rate of the first 230 gallons but did not provide data on the last 120 gallons. Since there are always a few gallons not traced due to clearances of the float measuring device, the computer program can be set to extrapolate the last stages of flow up to the total gallonage of the tank. The resulting ground pattern is compared with an actual pattern in Figure 39. Although this standard form of the program was used in generating the user guidelines, the match was not as faithful as we would normally expect. Since the last 120 gallons is influenced by a

change in tank geometry, some attempts were made to synthesize a better extrapolation of the flow-rate for the last third of tank evacuation.

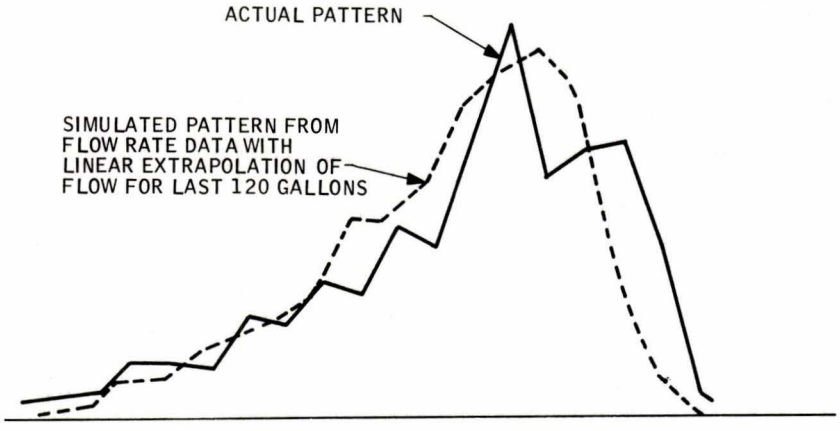


Figure 39. Comparison of Actual DC6B Pattern Marginal with Pattern Simulated by Flow-Rate

At the time of this study, we were still attempting to gain confidence in the predictive capability of the simulation and, consequently, the precision with which patterns could be predicted. The problem, therefore, was to determine, if possible, whether the matching problem was fundamental to the simulation, since it was later shown that the error introduced by the extrapolation was of no great significance in generating the guidelines.

Figure 40 shows the pattern generated for the first 230 gallons only, as compared with the actual patterns. The shaded area shows the pattern components contributed by the final 120 gallons. Figure 41 shows the same plot compared with the distribution generated by extrapolating the last 120 gallons. The figures show that the difference between the simulated and actual patterns can be accounted for by the

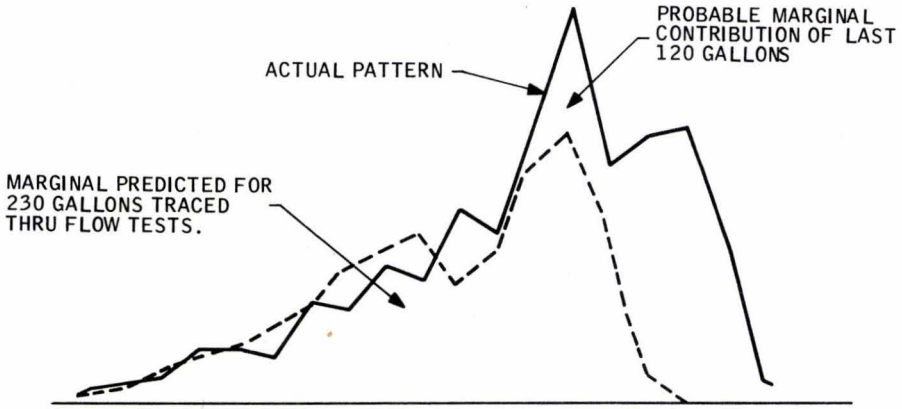


Figure 40. Comparison of Pattern Produced by First 230 Gallons with Actual Pattern

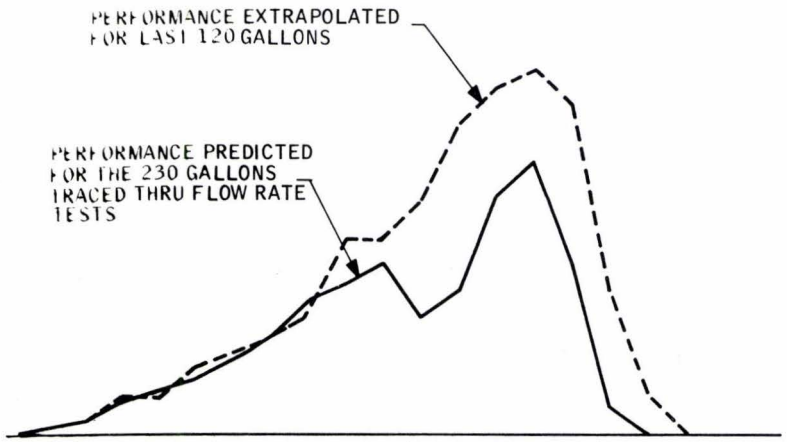


Figure 41. Contribution of the Extrapolated Flow-Rate of Last 120 Gallons to Total Simulated Pattern

redistribution of flow rate for the last 120 gallons. Unfortunately, the program that convolutes flow-rate downrange cannot be run backward; thus it is not possible to generate a flow-rate distribution from a pattern distribution, other than by iteration. One attempt to regenerate the flow rate by hand extrapolation from pattern difference data resulted in an overshoot -- the dip in the pattern was excessive, and the final 120 gallons ended up too far downrange.

It was concluded that the lack of precise flow data on the final 120 gallons was a reasonable explanation for the failure of the simulation to track the actual pattern. It was also concluded that the extrapolation procedure was adequate for generating guideline material. This type of problem, however, emphasizes the long-term importance of having a predictive flow rate simulation to back up the measurement program.

Hemet Valley S2F

A larger number of single-tank flow measurements was taken on the Hemet Valley S2F (Tankers 70 and 71). Many of the results were initially considered suspect in that the float appeared to stop and subsequently free-fall to the limits of the tank. Instrumentation difficulties were hypothesized to account for this situation since pressure buildup due to the venting configuration was minimal, on the order of 0.5 psi. This sort of pressure level had not, in prior experience, been associated with significant levels. In multiple-tank drops, a significant pressure buildup was noted.

Examination of the data showed that the float slowed considerably even if it did not halt on all but one of the flow tests. As a consequence, actual scope trace data were requested from the Forest Service for further evaluation.

Figures 42 through 44 show fluid surface versus time (trace 1) and pressure versus time (trace 2) for the three single-tank drops. Figures 45 through 48 show four drops in which the single tank was evacuated as a part of a trail-drop sequence. In other words, these data are roughly equivalent to a single-tank drop, as long as the two tanks were not released simultaneously.

The similarity of the performance of the fluid head is striking, with the only notably different performance seen in test 4-17. The flow-rate of test 4-17 is substantially that predicted by the Bernoulli flow-rate simulation. When a typical flow-rate (test 1-16) was compared with the pattern, the halting, then accelerating flow produced a large discontinuity that was not reflected in the pattern.

Examination of other drops in which two tanks and four tanks were released simultaneously showed similar phenomena in which the fluid surface slowed to a halt at proportionately higher hydraulic head levels, which appeared to relate to the higher pressure levels developed. (Figures 49 and 50.)

From data analysis it appeared that the fluid head hesitated (or halted) at fluid height roughly equivalent to the inches of fluid the negative pressure could be expected to support. Thus it was hypothesized that the tank evacuation made a transition from flow to a pop-bottling release. A 29-inch transparent tube was used to investigate this proposition (equivalent to the tank's hydraulic head). This resulted in two significant findings. First, the condition of head stoppage could be duplicated through restrictive venting and, second, that once the fluid's surface stopped, evacuation from the bottom occurred but not in the oscillatory pop-bottling mode. Instead, air entered in a repeatable parabolic, incursion displacing fluid along the sides. Using these observations, it became possible to synthesize a flow rate knowing the pressure drop.

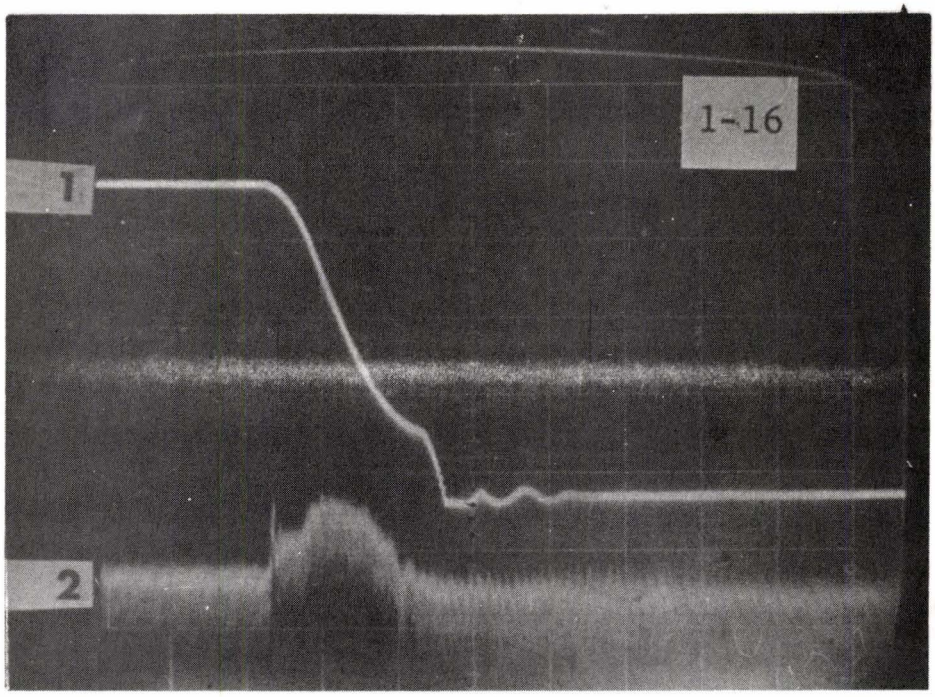


Figure 42. Pressure and Head Drop Data for Single-Tank Release 1-16

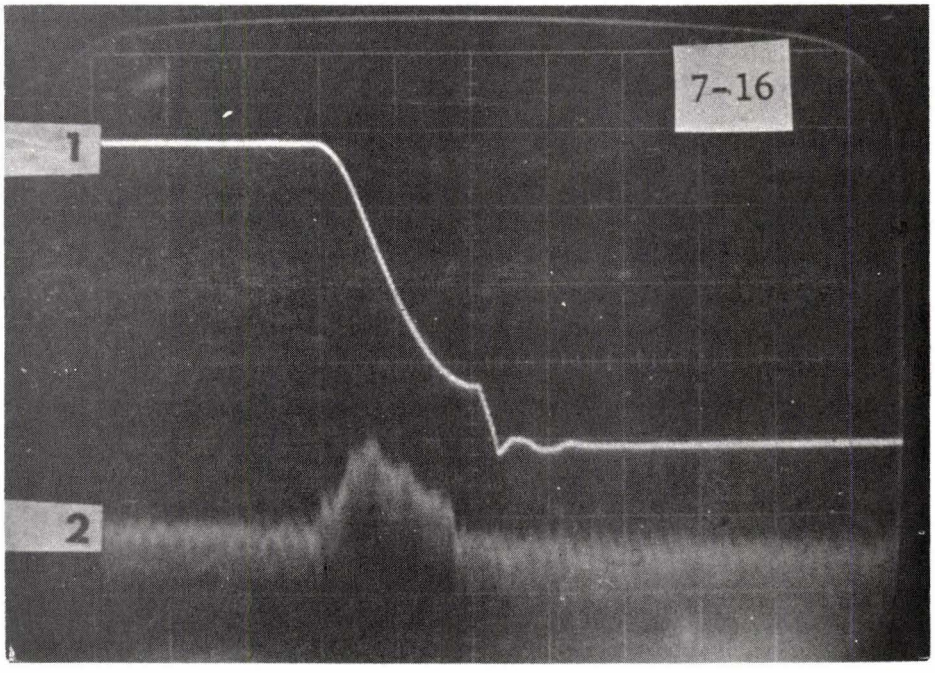


Figure 43. Pressure and Head Drop Data for Single-Tank Release 7-16

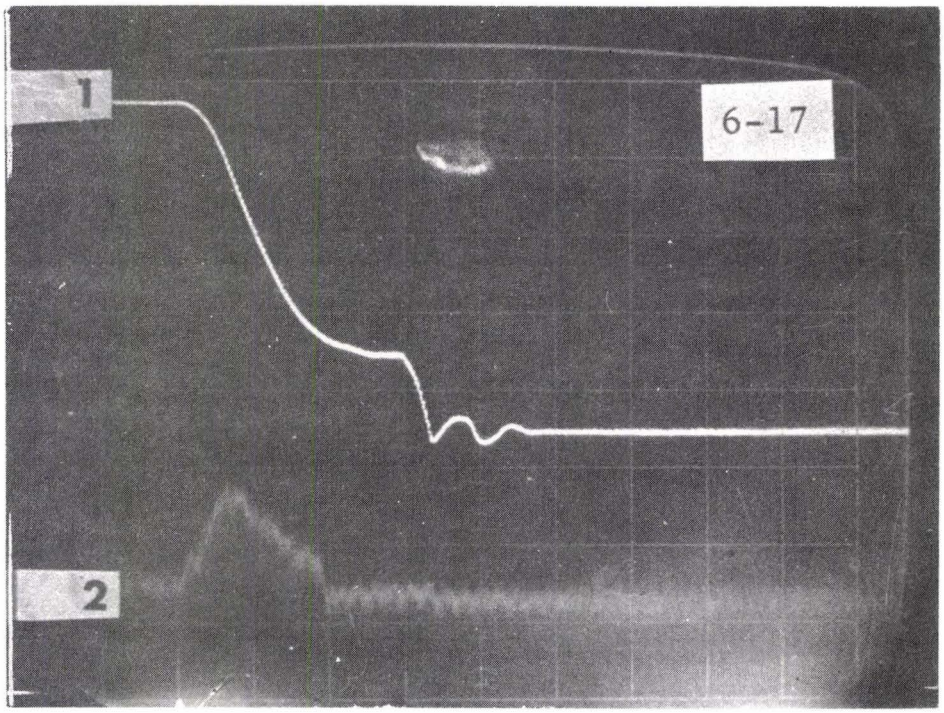


Figure 44. Pressure and Head Drop Data for Single-Tank Release 6-17

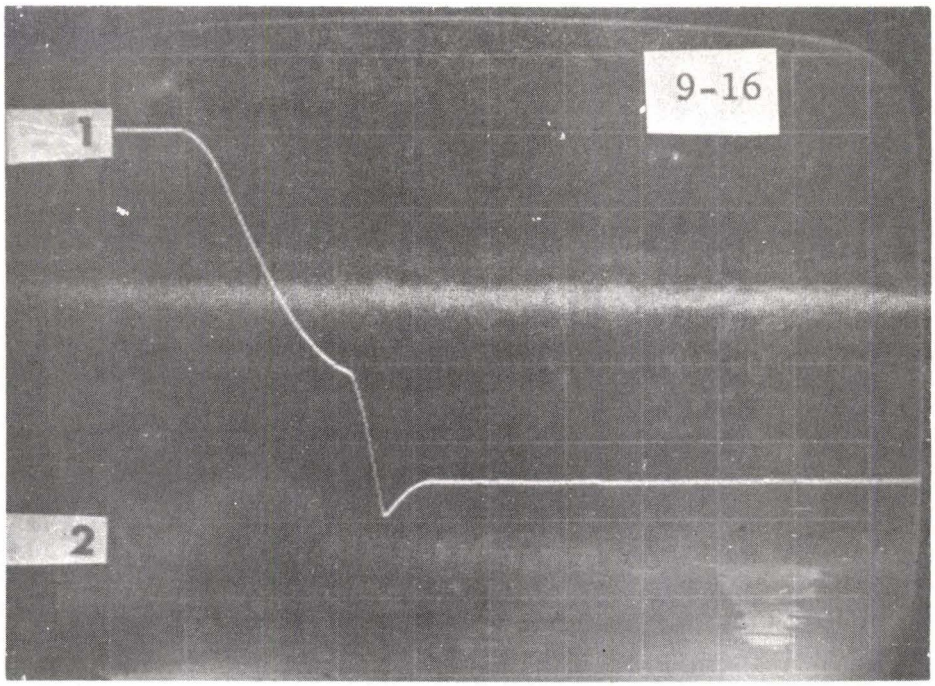


Figure 45. Single-Tank Flow Data in Four-Tank Sequence Drop 9-16 – Tank 1, 2, 3, 4; Tank 2 Flow

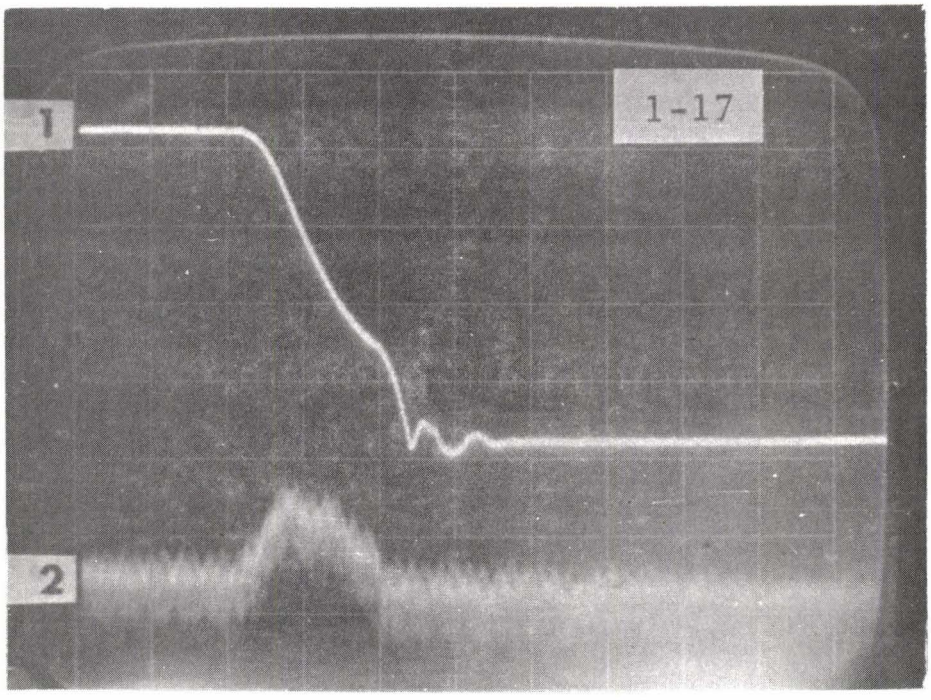


Figure 46. Single-Tank Flow Data in Four-Tank Sequence Drop 1-17 – Tank 1, 2, 3, 4; Tank 2 Flow

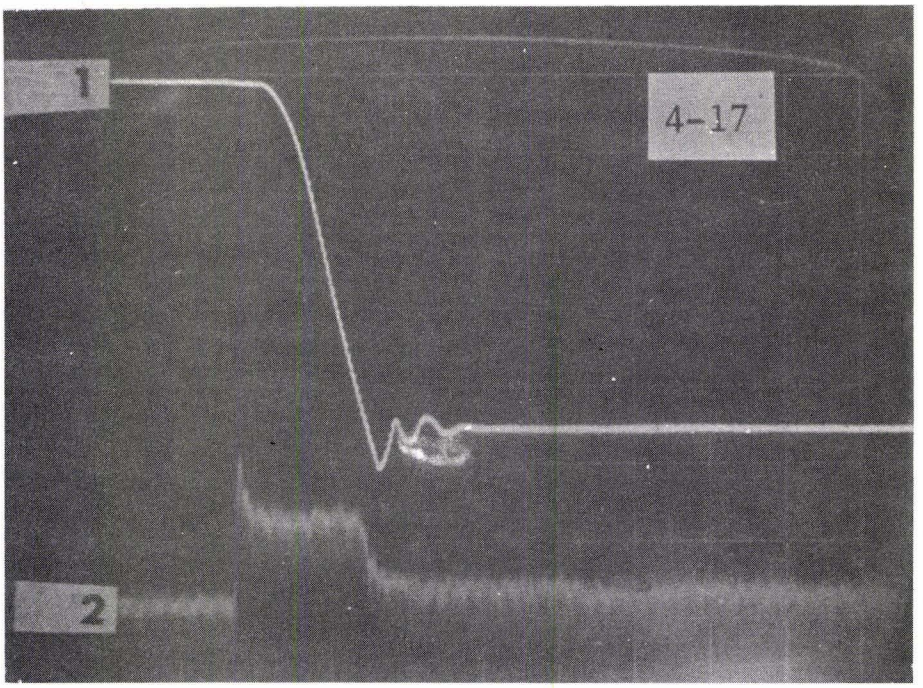


Figure 47. Single-Tank Flow Data in Two-Tank Sequence Drop 4-17 – Tank 2, 3; Tank 2 Flow

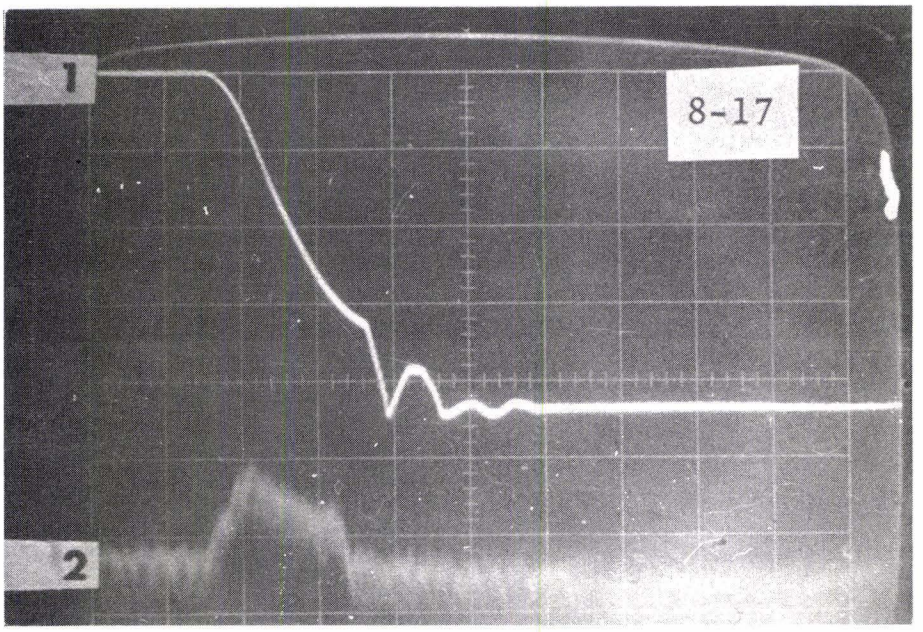


Figure 48. Single-Tank Flow Data in Two-Tank Sequence Drop 8-17 – Tank 2, 3; Tank 2 Flow

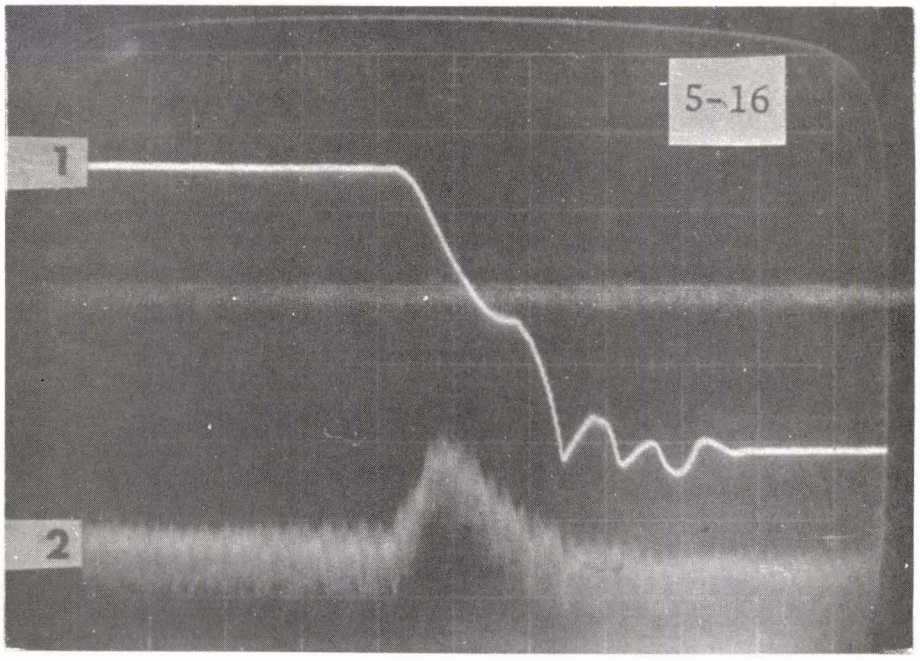


Figure 49. Typical Change in Evaluation Curves in Two-Tank Salvo with Common Vent

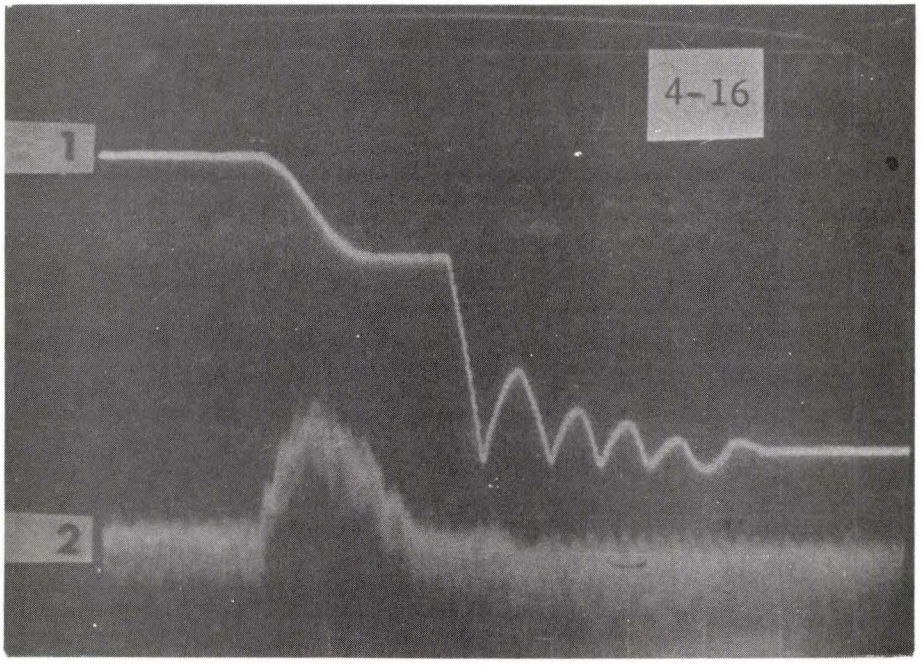


Figure 50. Typical Change in Evaluation Curves in Four-Tank Salvo with Common Vent

SYNTHESIZING THE FLOW-RATE

Figure 51 shows the methodology and hypotheses used to synthesize the flow-rate used in the guidelines. The first detail shows the tracing of the oscilloscope record of drop 1-16, with the pressure trace converted to inches of Phos-Chek. Note that the inches of fluid the pressure can support approaches the inches of fluid recorded by the float. Thereafter the float slows, but the pressure drops. If it is assumed that the pressure drop emanates entirely from the loss of head due to air incursion from the bottom, the tank evacuation is as shown in the details b and c. The flow rate of detail d is then hypothesized.

Application of the synthetic flow-rate to the pattern (Figure 52) shows a reasonable match.

Attempts to apply the approach to detailed analysis of other drops were not as rewarding. Loss of pressure differential does not necessarily coincide with terminal free-fall drop of the float measuring fluid surface. From a theoretical standpoint, this is not a contradiction -- once the evacuation by bubble incursion is established, this mode should continue even though pressure was equalized. The equalization of pressure would simply change the rate of bubble rise. The theory of bubble traverse is dependent primarily on the pressure differential in the fluid. It is thus only circumstantial that the technique of extrapolation worked adequately for the drop at issue.

The synthesized flow-rate was judged adequate for use in the generation of the guidelines. More significantly, however, the findings place a new emphasis on the relationship of tank venting to flow-rate performance. Specifically, the significance of a pressure buildup depends not so much on the value of the negative pressure but on the velocity of the fluid at the time the pressure buildup occurs. Much higher pressures

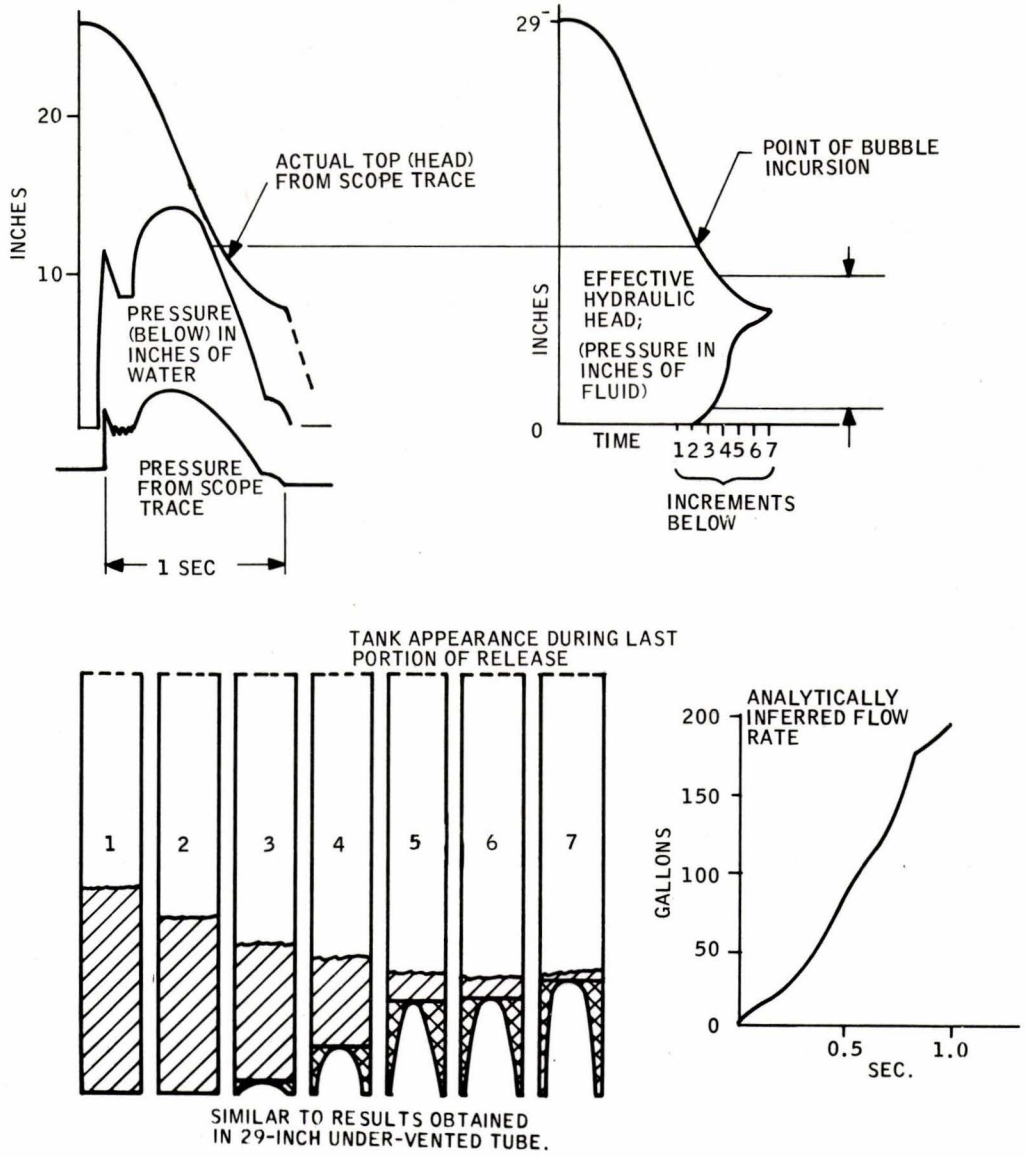


Figure 51. Method of Inferring Final Stages of Flow from Undervented S2F Tank

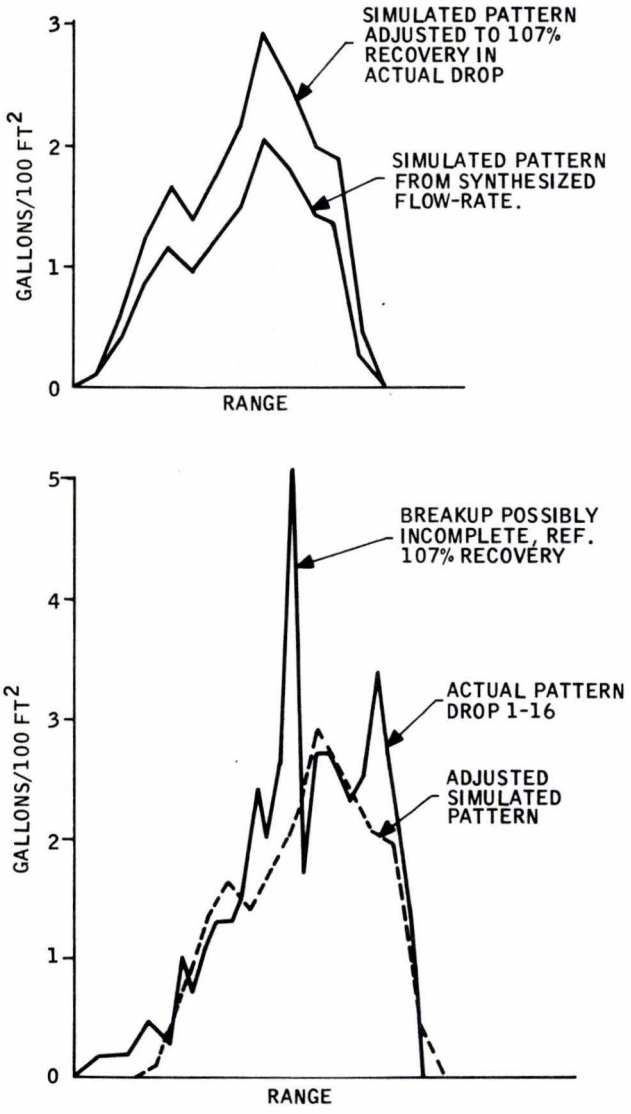


Figure 52. Comparison of Synthesized Flow-Rate Prediction with Drop 8 (95 feet)

(0.87 psi) were recorded in B-17 tests, but these occurred after the tank had developed considerable fluid velocity -- the tank did not shift to fluid displacement from the bottom. There is some evidence, however, even in the Aero Union B-17, that the pressure buildup modifies flow-rate. Thus, in any future flow-rate modeling, the effect of tank venting should be included. This is particularly evident when we consider that flow at any air velocity through an orifice will create a pressure drop that will tend to slow fluid evacuation. The significance of the pressure drop will depend on tank geometric characteristics under the dynamic conditions. It appears that such a subroutine could be introduced rather directly into the simulation. The resultant simulation could be expected to indicate the conditions under which pop-bottling might occur, but would not necessarily predict flow rates if pop-bottling happened.

REFERENCES

1. Swanson, D. H., and Helvig, T. N., "High-Altitude Retardant Drop Mechanization Study," Final Report, Vol. I, Contract 26-2888, 30 April 1973, Honeywell Inc., Government and Aeronautical Products Division, Hopkins, Minnesota 55343.

2. Ibid, Vol. II.

3. Swanson, D. H., and Helvig, T. N., "Extended High-Altitude Retardant Drop Mechanization Study," Final Report, Contract 26-2888, 10 January 1974, Honeywell Inc., Government and Aeronautical Products Division, Hopkins, Minnesota 55343.

4. Deeming, et al, "National Fire Danger Rating System," USDA Forest Service Research Paper RM-84, February 1972, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado.

5. Rothermel, R. C., and Philpot, C., "Reducing Firespread in Wild Land Fuels, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, July 1974.

6. Letter, Rothermel, R. C., to Swanson, D. H., 1 October 1974; Considers effect of retardant film thickness.

7. Grah, R. F. and Wilson, C. C., "Some Components of Rainfall Interception," Journal of Forestry, Vol. 42, pp. 890-898, 1944.

8. Zinke, P. J., "Forest Interception Studies in the United States," Forest Hydrology, W. E. Sopper and H. W. Lull (ed.), Pergamon Press, Oxford, 1967.

9. Anderson, W. H., Brown, R. E., Kato, K. G., and Louie, N. A., "Investigation of Rheological Properties of Aerial-Delivered Fire Retardant," Report 8990-04 (Final), to Northern Forest Fire Laboratory, U. S. Forest Service, June 1974.

APPENDIX A
PATSIM PROGRAM

PATSIM is a retardant ground pattern simulation program. The input and output were designed for ease of use. A small deck of input cards provide data on measured tank flow-rate, and these cards need not be changed from run to run. The remaining variable input consists of delivery speed, drop height, retardant type and number of tanks employed. The output consists of a graphic pattern representation, retardant contour quantities (gallons) and areas, and pattern-length data. An optional subroutine PATADD will also print out maximum line and the appropriate delay between tanks for sequential tank releases.

PROGRAM OPERATIONAL METHODS

The program retains seven operation methods, allowing a wide selection of the input descriptors of the tank to be simulated (Table A1). These include two modes where the tank is described geometrically, and flow-rate is calculated from door opening rate estimates using the Bernouli equations for steady state flow. (Comparison with actual measured flows shows that this technique is at best a rough approximation -- as is a consequence it is best to use actual flow data when an accurate prediction is desired.) The remaining run options, 3 through 7, enable the use of directly measured flow data -- total gallons released after each of a series of time increments. Experience has shown that door-opening rate data and ejection velocity data can be ignored with little effect on the accuracy of the prediction, therefore run mode 7 is recommended for most applications. It is also the mode requiring the least number of inputs.

Table A1. PATSIM Program Run Options

1.	Theoretical tank flow-rate, constant door opening rate (requires tank geometry input)
2.	Theoretical tank fow-rate, variable (polynomial) door rate (requires tank geometry input)
3.	Experimental tank flow data, quantity and door angle versus time (variable ejection velocity is used)
4.	Experimental tank flow data, quantity versus time, constant door opening rate (variable ejection velocity used)
5.	Experimental tank flow data, quantity versus time, variable (polynominal) door-opening angle (variable ejection velocity used)
6.	Experimental tank flow data, quantity versus time, constant ejection velocity
7.	Experimental tank flow data, quantity versus time, no door angle or ejection velocity input (program defaults to 16-fps ejection velocity)

One output option enables selection of the PATADD subroutine that calculates maximum line length and tank delay sequences for overlapping patterns in generating line.

PROGRAM INPUT

All input variables and constants are stored in an A-array. The variable numbers and constant names are equivalenced to locations in this array. The array location numbers are used when preparing input.

The format on an input card is:

Col. 1-10 : 1st variable number	Col. 11-20 : 1st variable number
21-30 : 2nd variable number	31-40 : 2nd variable number
41-50 : 3rd variable number	51-60 : 3rd variable number
61-70 : 4th variable number	71-80 : 4th variable number

All numbers are punched with decimal points and may be located anywhere in the field.

From one to four variables or constants may be entered on one input card. A completely blank card signals the end of one set of data or run. The variables need not be entered in any particular numerical order.

Another type of input card is used for comments or identifying titles. This card begins with an asterisk (*) in Column 1. Columns 2 through 80 of this card may be punched with alphanumeric information. This card is printed in the listing of input data given in the program. Comment cards may be entered anywhere in the input deck.

A typical input deck for operating from measured flow data is shown in Figure A1. Table A2 describes the input requirements for all seven operating modes. Definitions and dimensions of all input variables and constants can be found in the program glossary (Table A3). Aircraft tank descriptors are given in Figure A2.

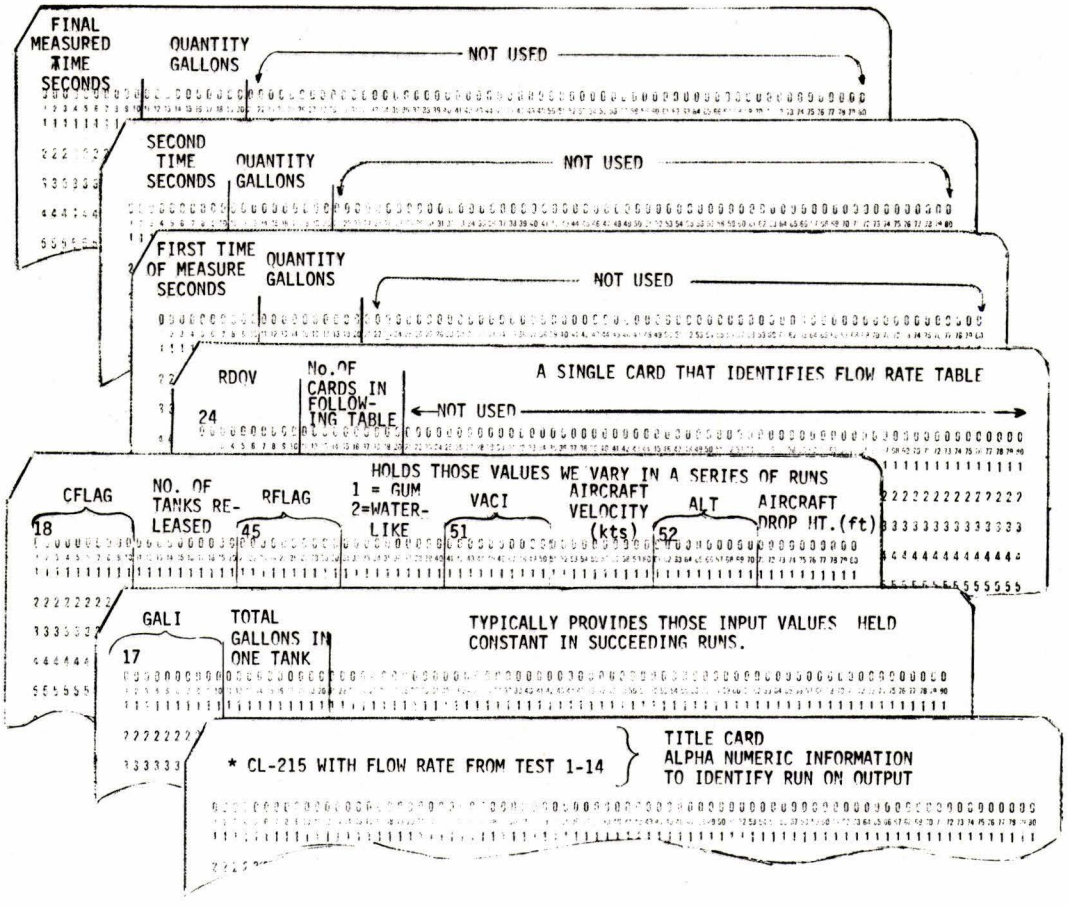


Figure A1. Typical Input Deck

Table A2. Program Input for the Different Program Operation Methods

Variable Number	Variable Name	Program Operation Method Number						
		1	2	3	4	5	6	7
1	ACFLAG	R	R					
2	ELT	R	R					
3	ELE	R	R	R	R	R		NO
4	B	R	R	R	R	R		NO
5	H	R	R					
6	CAPH	R	R					
7	HI	R	R					
8	WT	R	R					
9	SW0	R	R					
10	SW1	R	R					
11	SW2	R	R					
12	SW3	R	R					
13	PSII	R	R					
14	PHIO	R	R					
15	THMAXI	R	R		R	R		
16	THEP	R			R			
17	GALI	R	R	R	R	R	R	R
18	CFLAG	R	R	R	R	R	R	R
19	TMAX	NO	R	NO	NO	R	NO	
20	COEF (1)		R			R		
21	COEF (2)		R			R		
22	COEF (3)		R			R		
23	COEF (4)		R			R		
24	*RDQV	NO	NO	R	R	R	R	R
25	CONVEX	NO	NO	NO	NO	NO	R	NO
45	RFLAG	R	R	R	R	R	R	R
46	FNPAT	Optional - use for pattern overlaps only						
47	FNRAN							
48	FNCRAN							
51	VACI	R	R	R	R	R	R	R
52	ALT	R	R	R	R	R	R	R

* Tabular Input Required — Following the variable.

R Means input is required, blank means not required (but will not interfere with program operation) and NO means must not be used or program will not work properly.

Table A3. PATSIM Program Glossary (1 of 6)

Aircraft Tank Variables

Number (1)	Name	Description	Initial Value (2)	Units
1	ACFLAG	ACFLAG = 2., program uses CL-215 tank coding $\neq$ 2., program uses coding for remaining tanks	0	-
2	ELT	Tank length	0	ft.
3	ELE	Door opening length	0	ft.
4	B	Door width	0	ft.
5	H	Vertical measurement between door hinge and tank discontinuity.	0	ft.
6	CAPH	Initial head height when tank is full	0	ft.
7	HI	Height of first tank section	0	ft.
8	WT	Width of top of liquid when tank is full	0	ft.
9	SWO	Slope of tank sides	0	-
10	SW1	" " "	0	-
11	SW2	" " "	0	-

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table A3. PATSIM Program Glossary (2 of 6)

Aircraft Tank Variables

Number (1)	Name	Description	Initial Value(2)	Units
12	SW3	Slope of tank sides	0	-
13	PSII	Angle of tank bottom with horizontal	0	degrees
14	PHIO	Tank discharge angle measured from horizontal	0	"
15	THMAXI	Maximum door angle from horizontal	0	"
16	THEP	Door opening rate (if uniform rate is used)	0	rad/sec.
17	GALI	Total number of gallons in a tank	0	gallons
18	CFLAG	Number of tanks released	1.	-
19	TMAX	Poor opening time if polynomial is used. For uniform rate enter THEP value and make TMAX=O	0	sec.
20	$\bar{C}OEF(1)$	Coefficient of t^3 in door opening angle polynomial	0	-
21	$\bar{C}OEF(2)$	" " t^2 " " " "	0	-
22	$\bar{C}OEF(3)$	" " t " " " "	0	-

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table A3. PATSIM Program Glossary (3 of 6)

Aircraft Tank Variables

Number (1)	Name	Description	Initial Value(2)	Units
23	COEF(4)	Constant term in door opening angle polynomial	0	-
24	RDQV	Flag to select the option for input Q vs. T. Also the number of entries in this table. (See table description)	0	-
25	CONVEX	Constant exit velocity if this option is wanted. Otherwise use CONVEX=0	0	ft/sec.

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table A3. PATSIM Program Glossary (4 of 6)

Constants

Number (1)	Name	Description	Initial Value(2)	Units
31	AFLAG	AFLAG = 1., print ejection data = 0., do not print ejection data	0	-
32	BFLAG	BFLAG = 1., print bulk increment data = 0., do notprint bulk increment data	0	-
33	DFLAG	A print control - tells how many print lines to leave out	9.	-
34	EFLAG	Reduced memory flag. EFLAG = 1., reduced memory run (CM120000) EFLAG = 0., large memory run(CM300000)	1.	-
35	GFLAG	Not used	2	-
36	HFLAG	Not used	1.	-
37	ALF	Area reduction factor	.85	-
38	PP	Pressure	0.	lb/ft^2
39	$\overline{RHOI}$	Density of liquid	66.724	$Slugs/ft^3$
40	K1	Erosion factor	3.97	-
41	K2	Erosion factor	12.	-

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table A3. PATSIM Program Glossary (5 of 6)

Constants

Number (1)	Name	Description	Initial Value(2)	Units
42	DELT	Integration time interval	.002	sec.
43	TR	Number of time intervals for bulk liquid breakdown	10.	-
44	TX	Size of time interval for bulk breakdown	.02	sec.

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table A3. PATSIM Program Glossary (6 of 6)

Drop Delivery Variables

Number (1)	Name	Description	Initial Value(2)	Units
51	VACI	Aircraft speed	0.	knots
52	ALT	Aircraft altitude	0.	ft.
45	RFLAG	Retardant type flag. RFLAG = 1. means PHOSCHECK RFLAG = 2. means water and water-like retardants	1.	-
46	FNPAT	Number of overlapping patterns for multiple tank drops Use FNPAT = 1. or 0. for single tank drops.	0.	-
47	FNRAN	Displacement in range between pattern centers for multiple tank drops - number of cells(one cell = 30 ft.)	0.	-
48	FNCRAN	Displacement in crossrange between pattern centers for multiple tank drops-number of cells(one cell = 15 ft.)	0	-
18	CFLAG	Number of tanks released simultaneously. A multiplier of flow rate.	1.	-
53	ADD	Pattern Length for multiple patterns flag. If ADD > 0 means pattern lengths and time intervals are computed. If	0.	-
		ADD $\leq$ 0 pattern lengths and time intervals are not computed. See Note		

(1) The number is also the location in the A-array
(2) Initial value is set by the program

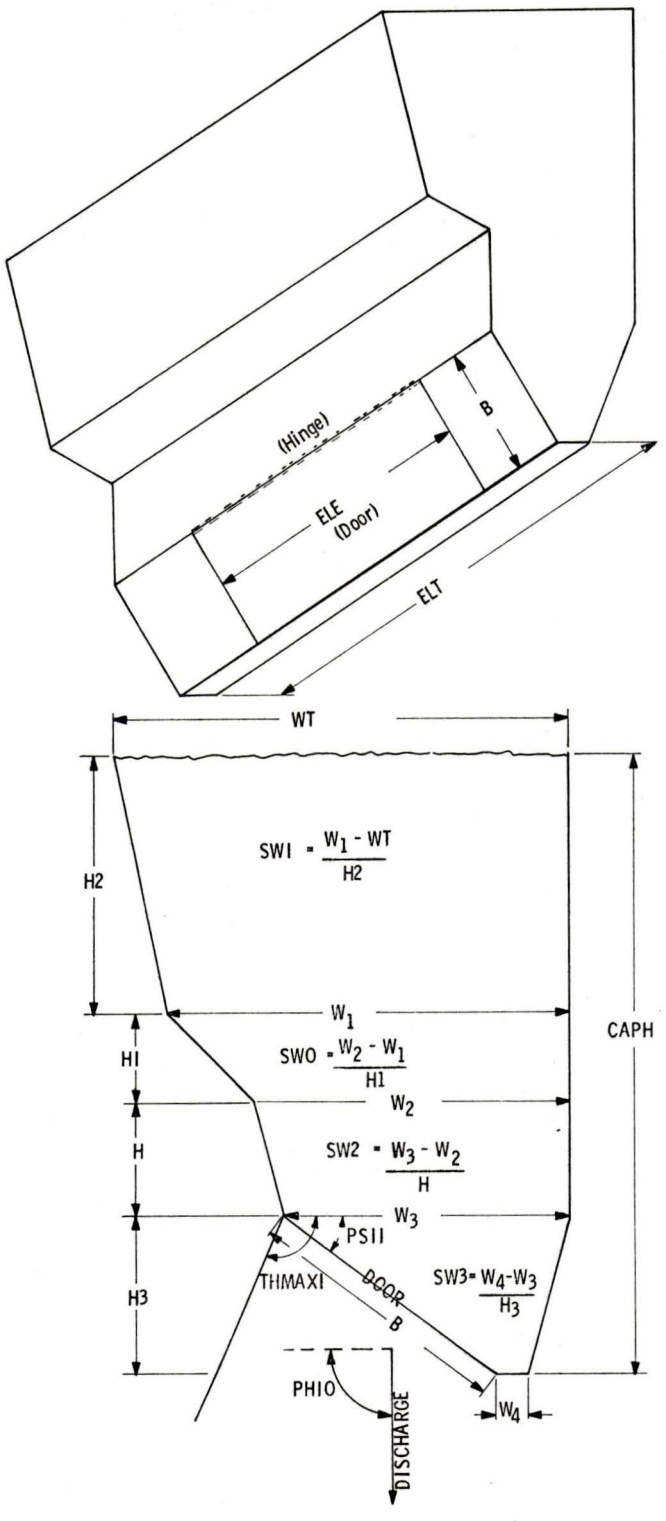


Figure A2. Aircraft Tank Descriptors

SPECIAL INSTRUCTIONS ON THE USE OF MEASURED FLOW-RATE DATA

Q versus T Table Format for Input Flow Data

When this option is used the RDQV variable must be on one card and the Q-versus-T table must immediately follow this card. There is one table entry per card as follows:

	Column 1-10	-	Time, sec.
	Column 11-20	-	Q, retardant quantity, gallons
Optional	Column 21-30	-	TMPS, door opening angle, degrees. If TMPS values are entered as zero, the original program options are used, i.e., constant door opening rate or cubic equation fit to test data.

The number of cards in this table is equal to the number following the RDQV variable number.

The time step size used in the input flow data may differ from the time step size used within the program. The program uses a relatively small time step size of 0.02 sec., whereas the input flow data step size may be larger (0.1 sec. for example). In this case the program will interpolate between time steps to provide data every 0.02 seconds. The interpolation for flow quantity is linear. The door opening angle used between input time points within the program is the average value for the larger input interval. The program will also extrapolate the flow quantity data based on the last two points in the input data. This extrapolation is extended linearly to the retardant quantity entered in the variable named GALI. This interpolation and extrapolation is

automatically done by the program whenever the variable RDQV is entered as a positive number. The program can be forced to use the data in it's input form (without interpolation or extrapolation) by entering the variable RDQV as a negative number.

Pattern Length and Time Interval Option (ADD Option)

If this option is used another input card must follow the variable number 53 card. This card contains a code in columns 1 to 8 that indicates the number of patterns to be added together. A "1" in a column means to add the column number of patterns. For example, "1101001" would compute single tank, two tanks, four tanks, and eight tanks.

PROGRAM OUTPUT

The output of the program, consists of the following:

- The input data
- A detailed pattern plot (Figure A3)
- Contour interval summaries (Figure A4)
- A scaled pattern plot (Figure A5)
- Pattern length data (Figure A4)
- The PATADD output, if used. (Figure A6)

.0	.0	.0	.2	.2	.2	.2	.0	.0	.0
.0	0.0	.2	.2	.2	.2	.2	.2	0.0	0.0
.0	0.0	.2	.2	.2	.2	.2	.2	0.0	0.0
.0	.2	.2	.2	.2	.2	.2	.2	.2	0.0
.0	.2	.2	.2	.3	.3	.2	.2	.2	.0
.2	.2	.2	.3	.3	.3	.3	.2	.2	.2
.2	.2	.2	.4	.6	.6	.4	.2	.2	.2
.2	.2	.3	.6	.9	.9	.6	.3	.2	.2
.2	.2	.4	.8	1.2	1.2	.8	.4	.2	.2
.2	.2	.5	1,1	1.7	1.7	1.1	.5	.2	.2
.2	.3	.6	1.4	2.3	2.3	1.4	.6	.3	.2
.2	.3	.7	1.7	2.8	2.8	1.7	.7	.3	.2
.2	.3	.9	2.2	3.6	3.6	2.2	.9	.3	.2
.0	.3	.9	2.4	4.0	4.0	2.4	.9	.3	.0
.0	.3	1.0	2.6	4.4	4.4	2.6	1.0	.3	.0
.0	.2	1.0	2.6	4.4	4.4	2.6	1.0	.2	.0
.0	.1	.6	1.6	2.5	2.5	1.6	.6	.1	.0
.0	0.0	0.0	.2	.2	.2	.2	0.0	0.0	0.0

Figure A2. Detailed Pattern Data in "Computer Scale"

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION
(GALLONS/100 SQUARE FEET)
TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0
48.4064	110.9556	116.5968	136.3993	60.5805	115.2700	0.0000	0.0000	0.0000

8.1-9.0	9.1-10
0.0000	0.0000

> 10
0.0000

TOTAL AMOUNT OF RETARDANT ON GRID = 588.21 GALLONS PERCENT OF TOTAL= 84.030
AVERAGE PATTERN LEVEL IS 2.2 GALLONS PER 100 SQUARE FEET

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION
(SQUARE-FOOT COVERAGE)
TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0
46800	24300	8100	5400	1800	2700	0	0	0

8.1-9.0	9.1-10
0	0

TOTAL AREA COVERED 89100 SQUARE FEET

> 10
0

PATTERN LENGTH DATA

480 FEET ABOVE	0.0 GALLONS/100 SQUARE FEET
330 FEET ABOVE	.3 GALLONS/100 SQUARE FEET
240 FEET ABOVE	1.0 GALLONS/100 SQUARE FEET
210 FEET ABOVE	2.0 GALLONS/100 SQUARE FEET
120 FEET ABOVE	3.0 GALLONS/100 SQUARE FEET
90 FEET ABOVE	4.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	5.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	6.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	7.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	8.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	9.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	10.0 GALLONS/100 SQUARE FEET

Figure A4. Summary Data Output (Sample)

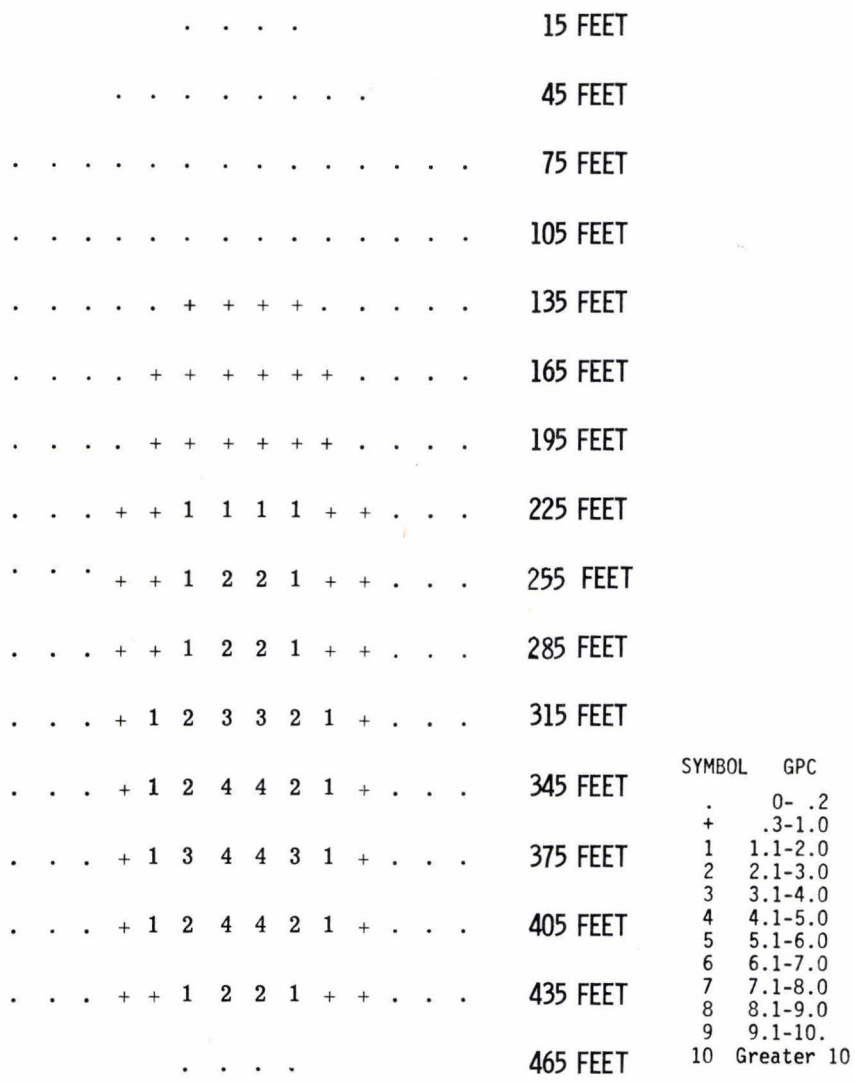


Figure A5. Pattern Data Output in True Scale

MAXIMUM LINE LENGTHS WITH CORRESPONDING TANK OPENING DELAYS

NO. OF	.5 GPC		1.0 GPC		2.0 GPC		3.0 GPC		4.0 GPC		6.0 GPC		8.0 GPC		10.0 GPC	
TANKS	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC
1	735	0.0	360	0.0	40	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2	1540	4.4	825	1.9	360	0.0	105	.4	40	0.0	0	0.0	0	0.0	0	0.0

Figure A6. PATADD Output

APPENDIX B
BASIS OF ACCURACY ESTIMATES

Formal accuracy studies require two basic sets of information, an error budget and a knowledge of the specific trajectory of the ballistic body being dropped. The error budget is a list of the uncertainties of the true release point in space, and their magnitudes, which are estimated. The trajectory enables the effect of these errors on the impact point to be evaluated in a perterbation study. The result of this study is a series of deltas (in feet) attributable to each source of uncertainty. If the errors are assumed to be normally distributed, the root of the sum of the squares of these deltas is the σ value of the error distribution. The probable error (or probable deviation) for the normal distribution is $0.6745\,\sigma$. The probable error measured with respect to the aircraft velocity vector is known as the Range Error Probability (REP). The probable error normal to the flight path is called the Deflection Error Probability (DEP).

We use a standard program on the Honeywell Computer Network to compute the probability of hit achieved by an area pattern with known major (range) and minor (crossrange) dimensions assumed to be centered on the point-mass trajectory. The program provides a numeric rather than analytic solution to the problem. The assumed normal range error distribution is divided into 10 equal probability areas. The pattern length is then centered on one increment, and the number of increments it covers is summed to yield the fractional coverage. The average fractional coverage for a pattern displaced to each of the 10 equal probability increments is the average fraction, $\overline{f}$, for errors on the range axis. The process is repeated in crossrange and the two values are combined as products:

$$f_{xy} = \overline{f}_x \times \overline{f}_y$$

A formal accuracy analysis would require a detailed trajectory analysis of each drop condition, and specific characteristics of the aircraft, which for the purposes of the guides is probably excessive since the end result is a probability statement subject to some interpretation; i.e., at what probability of hit do you decide not to accomplish a drop. The point of including probability-of-hit data in the guides is to illustrate that hitting a spot is probabalistic and varies with altitude. For this reason, it was decided to select a limit condition and generate a curve that would define this condition. A 60% probability of hit under a theoretical no-wind condition was selected as the limit condition. The problem was then reduced to defining the resulting curve.

An error budget was derived under the High-Altitude Delivery Program for use in perturbation studies to evaluate the effects of various tank option on system performance. This budget (Table B1) was developed by personnel familiar with aircraft delivery uncertainties and military accuracy analyses. (Another error budget was later developed by the Aerospace Corporation, but it was not used in this study due to the nature of the limit-line estimation and the availability of REP and DEP data already derived in prior perturbation studies.)

Trajectory studies were conducted under the High-Altitude Retardant Program on the CL-215 and Aero Union B-17. Although considerable differences were identified, the ability to relate these differences to tanking parameters (and, potentially, retardant type) remains an issue in the Experimental Tank and Gating Effort. Values used in the current study are based on the CL-215 trajectory in level flight. The trajectory and the results of the perturbation study are shown in Figure B1 and Table B2.

Table B1. Error Budget Used in Accuracy Estimates

Error Source	Error Magnitude at Drop Height of:	
	0-250 ft	250-1000 ft
Flight Errors		
A/C Velocity ($\Delta V_{A/C}$)	10 kts	10 kts
A/C Angle of Attack ($\Delta\sigma$)	2 deg	2 deg
Altitude (Δ Alt.)	50 ft	50 ft
Atmospheric		
Density ($\Delta\rho$)	+5%	5%
Aiming Factors		
Aiming Error (ΔAim)	10 mils	10 mils
Aim-Wander (ΔAim-W)	10 mils	10 mils
Wind Effects		
Crosswind (ΔXW)	1/3 wind velocity	1/3 wind velocity
Along Flight (ΔW)	1/3 wind	1/3 wind
Pilot Compensation, Crosswind (ΔXW Comp)	10 mils	10 mils
Pilot Compensation Along Flight (ΔW Comp)	10 mils	10 mils
Human Error		
Time (ΔT)	0.2-sec delay	25% or 1/2 sec

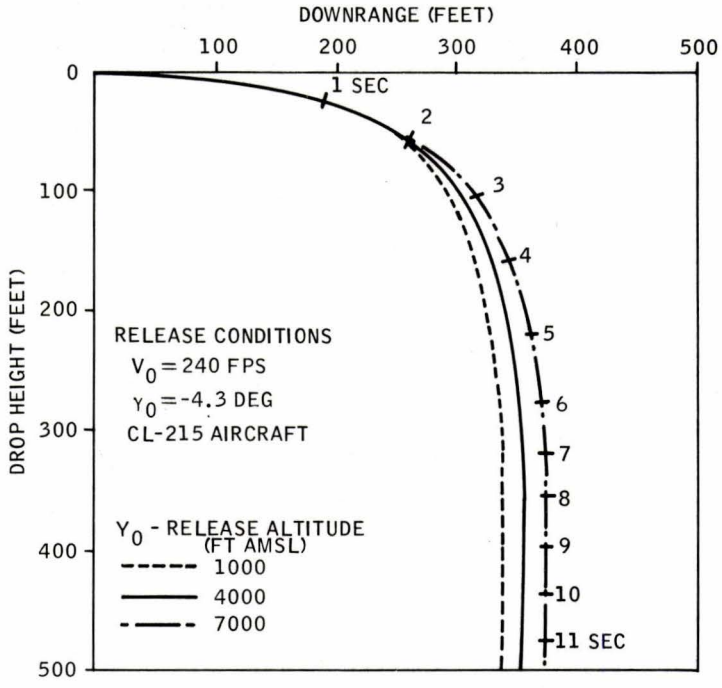


Figure B1. Trajectory Used in Perturbation Study

Table B2. Results of Perturbation Study (Δ values in feet)

Alt (ft)	1 AV_{AC}	2 Δσ	3 Δ Alt	4 Δρ	5 Δ Aim	6 Δ Aim-W	7 Δ W	8 Δ W Comp	9 Δ T	10 Δ X W	11 Δ X W Comp
150	7	5	0	4	11	11	70	35	48	53	26
250	7	3	10	8	12.1	12.1	120	60	48	100	50
400	7	2	5	10	22.4	22.4	225	112	72	187	94
500	7	2	0	10	28.0	28.0	295	148	72	232	116
700	7	2	0	10	39.4	39.4	395	198	72	344	172
1000	7	2	0	10	55.7	55.7	560	280	72	460	230

Perturbation errors can be summed to include or exclude different sources of error. The range error used is the root square of columns 1 through 6 in Table B2 and column 9, the human error associated with the point of release.

The crossrange error in the theoretical no-wind conditions is defined as the product of the slant range and the aiming errors in mils and results in the following tabulation (values in feet):

Drop Height	Aim	Aim Wander
150	5	5
250	5.1	5.1
400	9.5	9.5
500	11.8	11.8

Note that, if crosswind is included, an additional error accumulates according to the formula

$$C_R = V_{wind}\left(\text{time of fall} - \frac{X_{range}}{V_o}\right)$$ (Ref. BRL 1047, April 1958)

These data were used to extrapolate REP, DEP, and σ values for 300- and 500-foot drop heights resulting in the following schedule:

Drop Height	Range		Crossrange	
	σ	REP	σ	DEP
150	55.1	37.2	7.1	4.79
300	61.9	41.8	9.2	6.21
500	83.1	56.1	17.0	11.47
700	92.5	62.4	24.0	16.19
1000	107.7	72.6	34.0	22.93

These error values were used in the program to determine probability-of-hit curves.

The Honeywell Program was then run for pattern lengths of 50, 100, 200, 300, 400 and 500 feet, all with a pattern width of 60 feet. Results, in terms of probability of hit (P_H), are plotted in Figure B2. When cross-plotted (Figure B3) at a constant probability of hit, the region is sparsely defined. No attempts were made to refine the values due to the nature of the estimates and the computational processes involved.

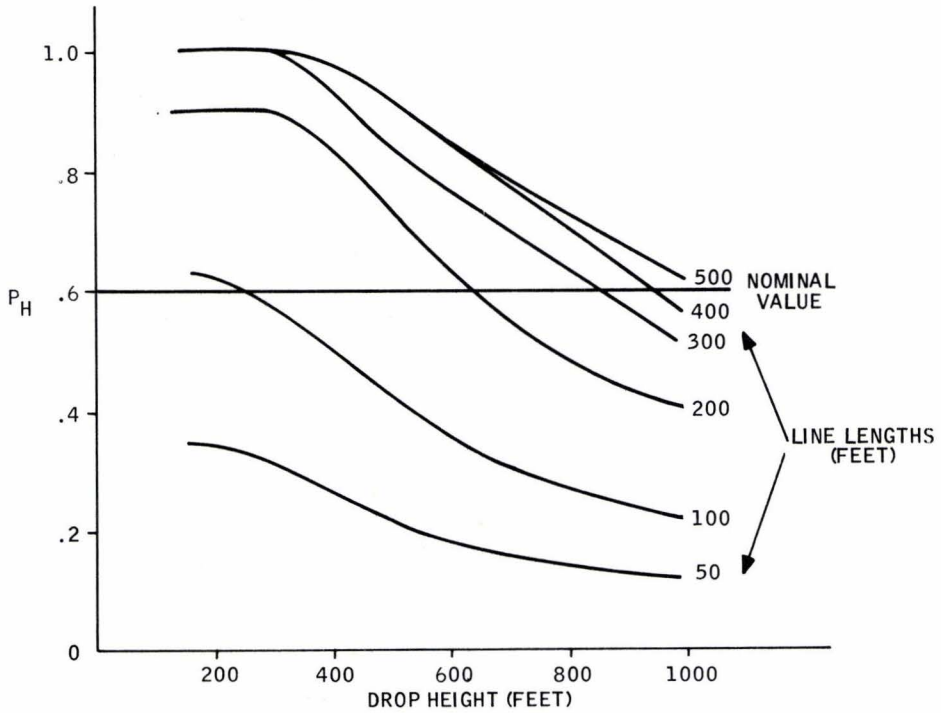


Figure B2. Probability of Hit for Various Pattern Lengths and Drop Heights

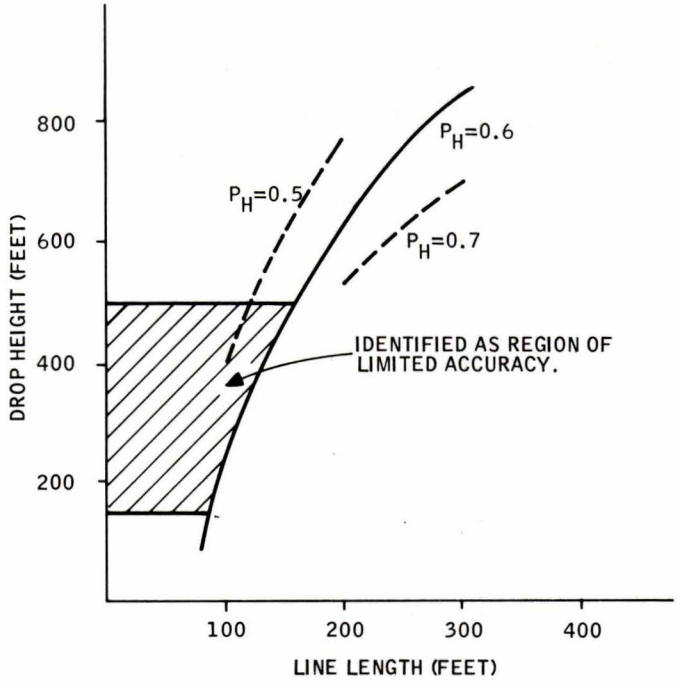
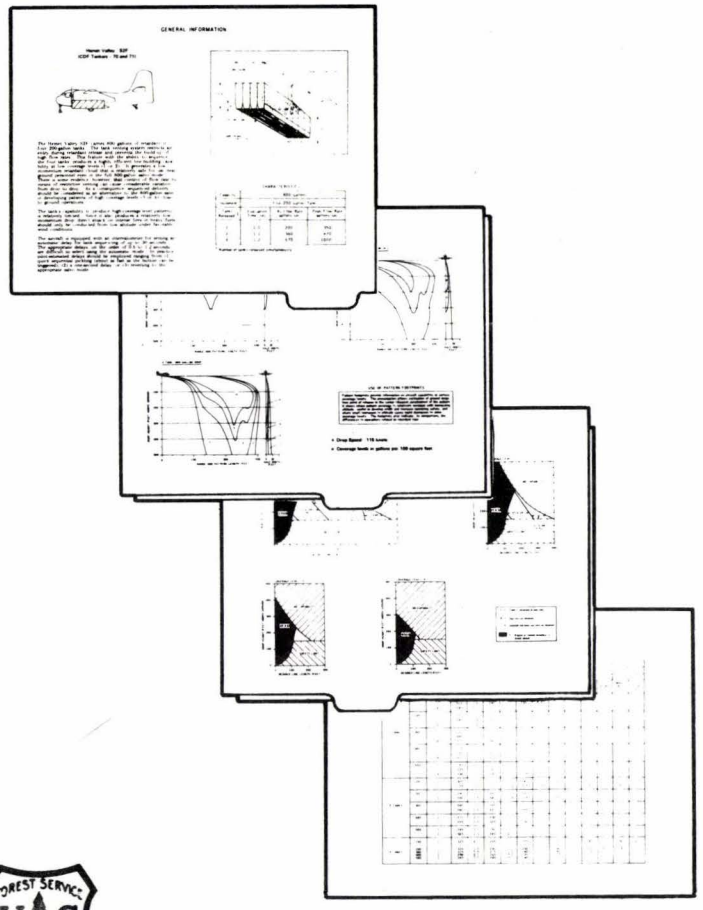


Figure B3. Cross Plot of Line Length versus Drop Height at a Probability of Hit of .6

ATTACHMENT 1

GENERAL INSTRUCTION MANUAL
FOR
RETARDANT DROP USER GUIDES



USER GUIDELINES for FIRE RETARDANT AIRCRAFT: GENERAL INSTRUCTION MANUAL

PREPARED BY HONEYWELL INC.

and

THE NORTHERN FOREST FIRE LABORATORY

for

U.S. DEPARTMENT OF AGRICULTURE

FOREST SERVICE

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

A REPORT OF RESEARCH PERFORMED UNDER THE AUSPICES OF THE INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION, OGDEN, UTAH.

Honeywell

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USER GUIDELINES FOR FIRE RETARDANT AIRCRAFT:

GENERAL INSTRUCTION MANUAL

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15 February 1975

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Intermountain Forest and Range Experiment Station
USDA Forest Service
Ogden, Utah

This manual is published as a part of a program to improve fire control technology, specifically through the use of fire retardant chemicals and delivery systems whose chemical and/or design characteristics are tailored to fuel and fire situation needs. This program is being conducted at the Northern Forest Fire Laboratory. Information or questions regarding these studies should be directed to the:

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Introduction

This Manual, in combination with the various User Guides for individual tanker aircraft, is intended to:

- Introduce a systematic basis for retardant tanker mission planning so that specific airtankers can be employed in the most effective manner based on their inherent capabilities or limitations and the local fire/fuel situation.
- Provide (in association with other guidelines as they are developed) the ability to relate effective performance achieved by one tanker to the inherent capabilities of other tankers that may be brought into the area.
- Introduce a procedure for after-the-fact evaluation of tanker operations so that the most effective retardant drop conditions for the local situation can be identified in a quantitative fashion.

Air tankers differ considerably in their capabilities and limitations because of tank design characteristics, tank sequence options, retardant quantities, and aircraft flight envelopes. When the unique characteristics of an aircraft, in concert with the locally available retardant and usage patterns refined over years of practical experience, are singularly effective in a local fire/fuel situation, that aircraft will become an acknowledged favorite. A different aircraft when asked to perform in the habitual way, may appear totally ineffectual by comparison, even though it too may be a favorite in other regions where different usage patterns, retardants or the like tailor its performance to the particular drop situation.

Recently, considerable advances in the understanding of why tankers perform as they do has been gained in work at the Northern Forest Fire Laboratory. If we know what makes a good drop from one aircraft in a given local situation, we can adjust the usage pattern of a different aircraft to most closely approximate performance of the favored tanker. We can also begin to recognize situational changes from day to day or hour to hour that influence delivery conditions—that change the drops delivered in identical ways from excellent to poor between morning and afternoon.

Despite advances in tanker understanding there are still many unknowns which are related first and foremost to the local fire situation. Perhaps this is as it should be, since broad generalizations often obscure critical issues best comprehended by the personnel with local responsibility. For this reason many of the baseline values issued in these guidelines are suggested points of departure that should be refined based on experience and a certain amount of intelligent experimentation. The guidelines will, if properly used, provide a method of quantitatively assessing the good drops versus the bad drops in postmortems of operations.

For example, if your favorite aircraft is covered by the guides available, think back to a drop that was particularly effective. By estimating drop height at tank release you can determine from the curves presented the pattern value and certain other characteristics of the pattern thus generated. These characteristics, then, provide the critical viewpoint by which we refine our intuition and subsequently attempt to tailor the performance of airtankers for most effective usage. Record keeping is thus encouraged as an integral part of guidelines application.

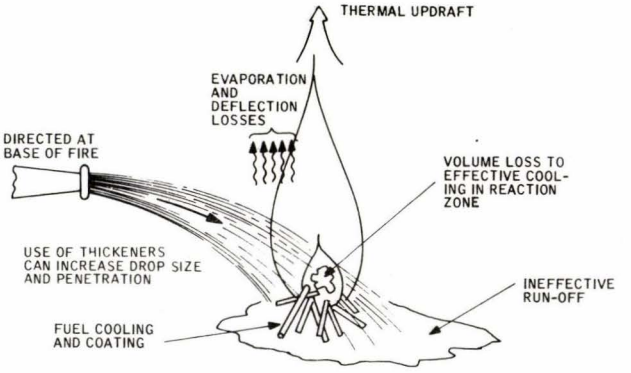
Although experience has been cited above as a method of optimizing usage patterns for the local situation, we do not mean to imply that better ways of using even favorite aircraft cannot be found. Indeed, some of the views presented here may seem inconsistent with your understanding of aerial fire fighting—and they may well be. Nonetheless, our views, intuitions and habits of employing the airtanker have evolved from the water bomber to current retardant aircraft. They are weighted heavily by the preponderance of TBMs and other low-capacity aircraft. They are influenced by our understanding of fire fighting with conventional hoses (and there are both similarities and startling differences). To this extent, current best usage practices of aircraft may be less than optimum. This document then provides, in addition to guidelines, a basis for experimentation, so that even better usage patterns can be identified for more efficient and effective fire management through the use of airtankers.

Conventional Firefighting Has Some Similarities to Airtanker Attack

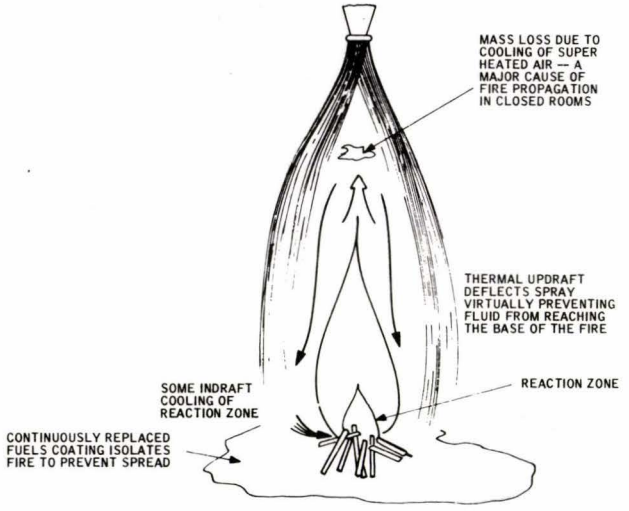
Conventional fire fighting uses the continuous application of retardant or water to drive the fire to total extinction by several means:

- Cooling fuels and gases near the reaction zone.
- Coating fuels surfaces to deprive the surface of heat and oxygen.

Optimized techniques attempt to tailor application rates (gallons/sec) to reduce time of application by minimizing run-off—the amount of material that is not effective in achieving extinction.


THERMAL UPDRAFT
EVAPORATION AND DEFLECTION LOSSES
DIRECTED AT BASE OF FIRE
VOLUME LOSS TO EFFECTIVE COOLING IN REACTION ZONE
USE OF THICKENERS CAN INCREASE DROP SIZE AND PENETRATION
INEFFECTIVE RUN-OFF
FUEL COOLING AND COATING

A Sprinkler System Operates from Above the Fire-Illustrating Both the Problems and Principles of Airtanker Attack


MASS LOSS DUE TO COOLING OF SUPER HEATED AIR -- A MAJOR CAUSE OF FIRE PROPAGATION IN CLOSED ROOMS
THERMAL UPDRAFT DEFLECTS SPRAY VIRTUALLY PREVENTING FLUID FROM REACHING THE BASE OF THE FIRE
REACTION ZONE
SOME INDRAFT COOLING OF REACTION ZONE
CONTINUOUSLY REPLACED FUELS COATING ISOLATES FIRE TO PREVENT SPREAD

A sprinkler system is not generally credited with the capability of direct suppression since the thermal up-draft protects the flame like an umbrella. Instead it operates against the fire-spread mechanisms by cooling the superheated air and "fire-proofing" adjacent fuels.

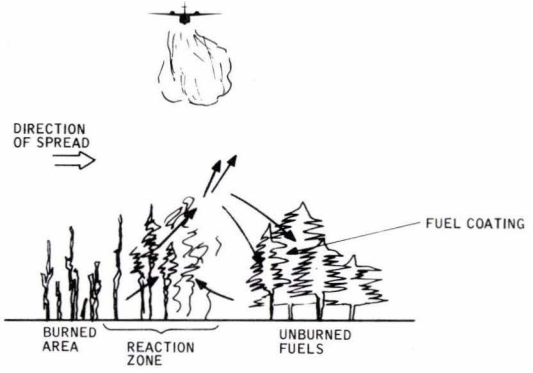
Thickeners have been shown to increase drop size, and consequently their penetration into the fire plume.

Similarities and Differences

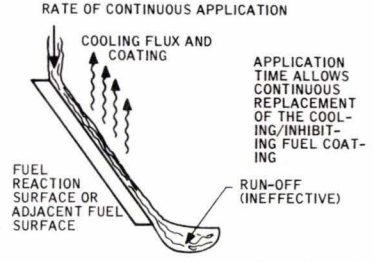
The airtanker attacking the fire from the top is similar in some respects to the sprinkler. The combination of a driving wind and thermal updraft largely deflect drops toward the fuels in front of the fire.

Unlike the sprinkler mass losses taken in cooling superheated air above the fire do little to reduce the spread rate since radiation from the convection column does not contribute significantly to fire spread.

Fuel coating (from water content and thickners), fuel modification (from the retardant salts) and fuel cooling (from the water content) are the major effects achieved in a major fire situation.

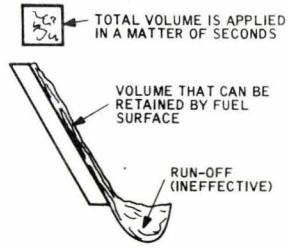


Conventional fire fighting uses time of application to cool or starve the fire to extinction.


RATE OF CONTINUOUS APPLICATION
COOLING FLUX AND COATING
APPLICATION TIME ALLOWS CONTINUOUS REPLACEMENT OF THE COOLING/INHIBITING FUEL COATING
FUEL REACTION SURFACE OR ADJACENT FUEL SURFACE
RUN-OFF (INEFFECTIVE)

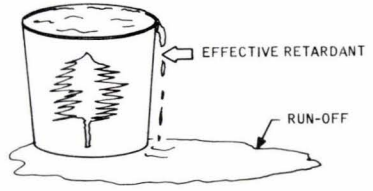
(RATE) X (TIME) - (RUN-OFF) = EFFECTIVE VOLUME

Air delivery applies all the retardant at once and must rely on the fuel surface to retain an adequate amount to extinguish, knock down or retard the fire.



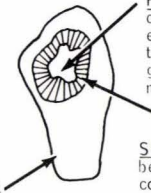
Effective volume is only that which can be retained by the fuel surface. The addition of thickening agents can increase the volume retained on the fuel and slow run-off.

Since the fuel surfaces are limited in the amount of retardant they can retain, any excess application will ultimately be lost ineffectively as run-off.



This factor places practical limits on the useful coverage levels in retardant ground patterns.

It also means that in most cases of direct attack; retardant effects on adjadcent fuels are as significant as those on the reaction zone itself.



FIRE: Although dripping and running prolong the continuous effects of the brief application the total effect is limited to what can be achieved in something less than one minute -- few fires are extinguished by conventional techniques in a matter of minutes regardless of application rate.

LONG-TERM BENEFITS: The retardant salts continue to alter pyrolysis of combustion mechanisms long after the water content has been dissipated. This effect becomes more significant in aerial retardant delivery than the benefits of fuel cooling and coating from the water content of the fire alone.

SHORT-TERM BENEFITS: Limits of the short-term benefits of fuel cooling and coating from the water content of retained retardant. If the effect lasts long enough to resist fire spread to new fuels, delayed extinction will result.

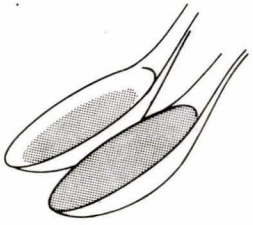
Recommended Coverage Levels

Based on studies of fuel surface capacities, retardant salt effects, moisture damping effects, and experience—knowledge of the pattern capabilities of aircraft known to be effective in certain fuel situations—the following coverage levels can be identified. They are related to fuel models contained in the National Fire Danger Rating System.

Coverage Level	Recommended For:	
	Fuel Model	Description
1	A	Grasses; tundra, and open desert shrub lands
2	C	Conifer timber with grass understory
	F	Brushfields with much green material
3	D	Shrublands under 6 feet in height (such as sagebrush)
	E	Hardwood litter after leaf drop
	H	Closed conifer timber with litter only
4	B	Hard chaparral and other high (6-foot) flammable shrubs
	G	Closed, old conifer timber with litter and dead, down limb wood.
	I	Conifer slash

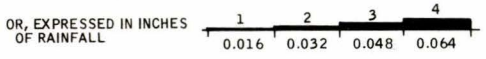
For creeping or smouldering fires reduction of one coverage level may be considered.

Coverage levels are expressed in gallons per 100 square feet (sometimes abbreviated gpc, gallons per C, the Roman numeral for one hundred). They are derived from the fuel surface area and the effect of retardant salts on spread rate in typical fuels. They are tempered by knowledge gained in experience from the capabilities of aircraft known to be effective in certain fire situations. For example, the Bureau of Land Management has considerable confidence in the use of trail systems against grass fires. Such systems produce considerable line at levels ranging from .5 to 2 gallons per 100 ft^2 and little coverage at higher levels.



ONE GALLON PER 100 SQUARE FEET IS ABOUT 1 1/2 TABLESPOONS SPREAD EVENLY ON THIS PAGE.

EVEN AT HIGHER COVERAGE LEVELS THE AMOUNT IS NOT GREAT -- IT IS EQUIVALENT TO THE DEPTH OF MATERIAL BELOW

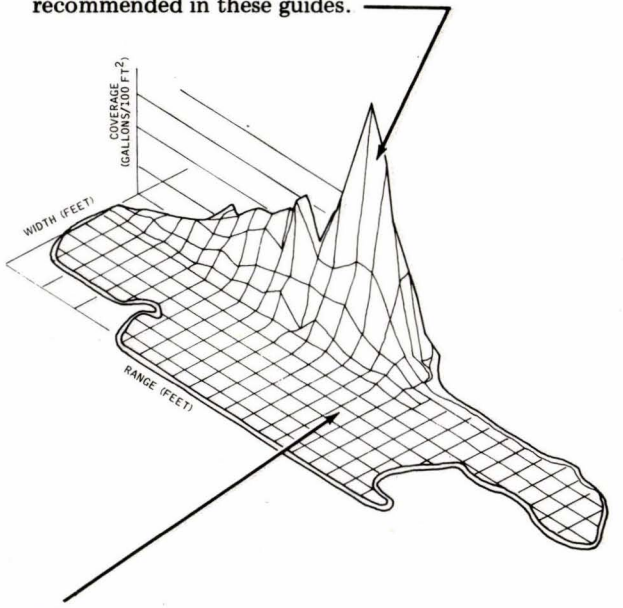


Retardant Patterns

A retardant pattern is an area map of the way the material is distributed on the ground in terms of effective coverage levels. It is a way of representing the characteristic splash pattern of the retardant dumped from an aircraft. It provides a way of evaluating the effects of the drop on the fire/fuels of interest by examining the area, length, and width of the pattern at its various coverage levels.

This three-dimensional representation of the retardant pattern resembles a mountain range emerging from a plateau. It shows how the coverage level, measured in gallons per 100 square feet, fluctuates over the drop area. The coverage level is greatly exaggerated here in the vertical scale.

- The mountain range contains the coverage levels of 1 to 4 recommended in these guides.



- The plateau represents a very low coverage level or trace precipitation, typically about 1/10 of the lowest recommended coverage level.

Evaluating Pattern Effectiveness

When presented in terms of an elevation map with lines bounding the areas at or above specific coverage levels, the pattern's effectiveness can be evaluated in various fire situations.

- Considerable areas of the pattern are at coverage levels in excess of that required. They are effective, but the excessive gallonage could be better used if spread over a larger area.
- Some areas are inadequately covered. They have more limited effectiveness and may in many cases be ignored.

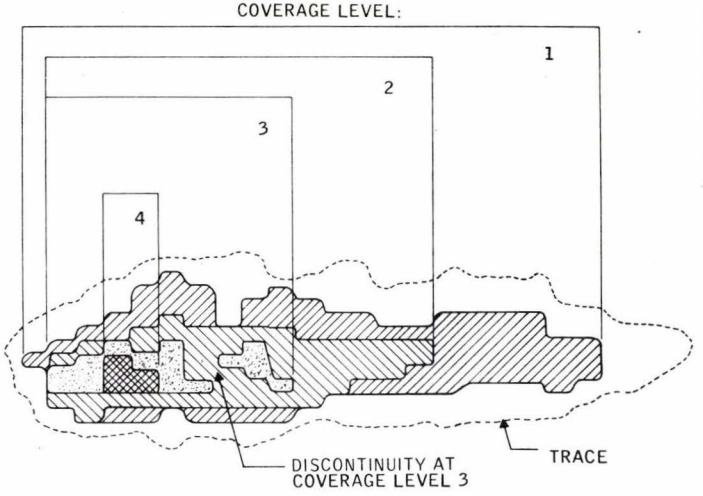
There are three important characteristics of any pattern.

- Length at a given coverage level.
- Width at a given coverage level.
- The momentum of the retardant mass as it falls to the ground.

LENGTH is a direct measure of the line applied in front of the fire. It is also the pattern dimension that accommodates range errors in placing the pattern accurately. Length is controllable by proper selection of the tank release options available to the pilot.

WIDTH is the pattern dimension that accommodates cross-range errors in placing the pattern. Its influence on the fire is difficult to evaluate quantitatively, and it is not generally controllable. Increased width is viewed as a benefit, rather than a dominant variable, in these guidelines.

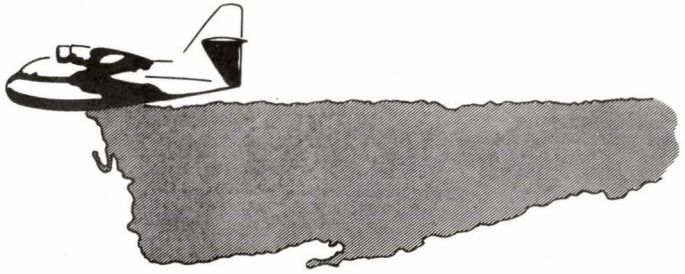
MOMENTUM refers to the velocity and mass of the retardant as it approaches the ground. It determines where the central core of the pattern will land with respect to the drop point. High-momentum drops shoot far down range from the release point, resist wind deflection, and penetrate most fire plumes. They yield small areas at very high coverage levels and have the potential to physically break fuel structures (top trees, etc.). As a consequence they are potentially dangerous to ground personnel. The high-momentum portion of the pattern contributes to accuracy and is usually limited to the lower drop heights.

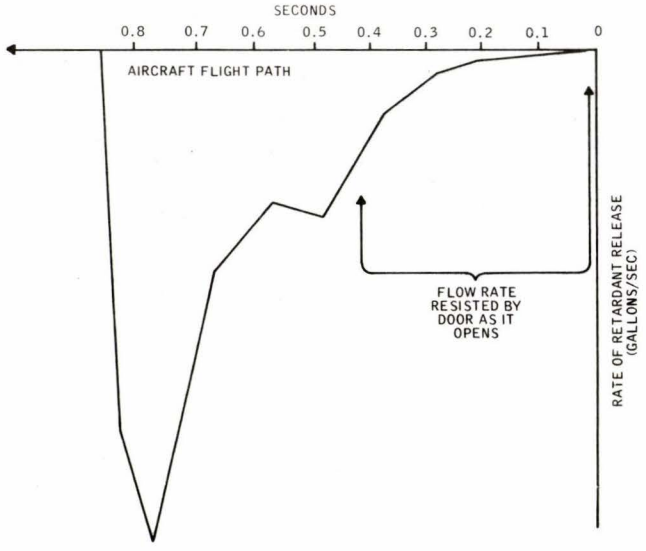


Volume Flow Rate Establishes Tank and Gating System Performance

The characteristic volume flow rate from the tank determines pattern performance. Aircraft velocity, altitude, and retardant type, simply modify the recovered values of the retardant distribution achieved on the ground.

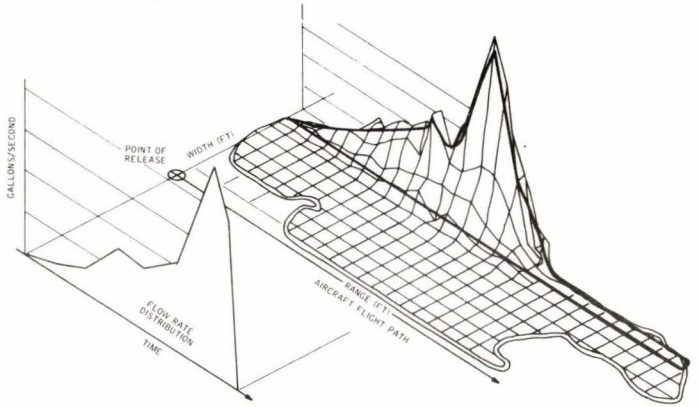
The flow rate from the CL-215 for example, has the basic form shown below, which is determined by tank geometry, door opening rate, venting and door area.



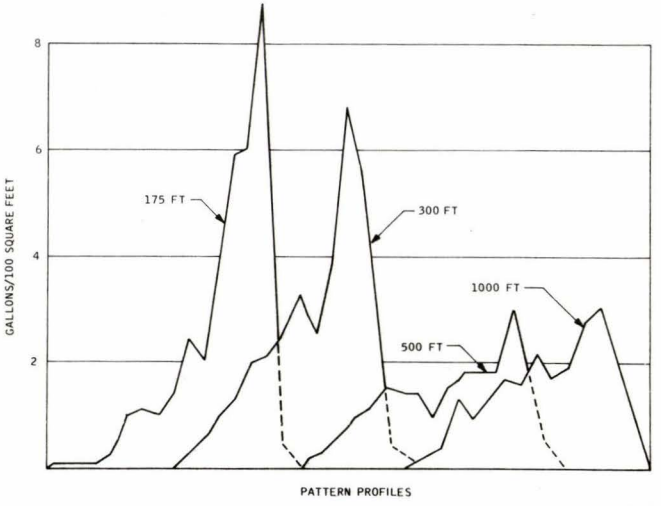


Flow-Rate-Determined Pattern Characteristics Are Visible in Recovered Ground Patterns

The three-dimensional plot below shows how flow-rate distribution is reflected in the ground-coverage pattern.



Flow-determined characteristics are retained regardless of the altitude even though actual coverage levels are reduced as the retardant spreads out in width, and loses material due to evaporation.



Factors Controlling Pattern Coverage Levels

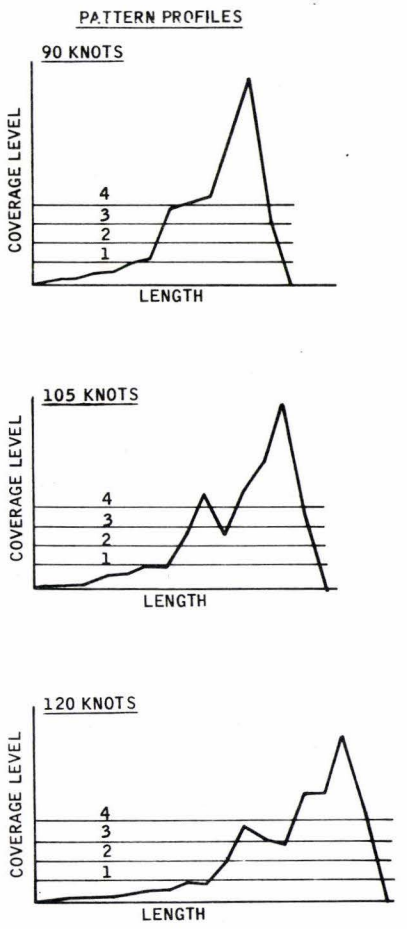
The flow rate from a single tank is fixed by quantity, door-opening rate, tank geometry, venting and door area. The distribution of retardant in the pattern can be controlled to a limited extent by the selection of aircraft drop height, velocity, and angle of attack.

DROP HEIGHT — Increased drop height has the general effect of reducing the peak coverage level and momentum of the pattern, and increasing pattern width. Its effect on pattern length ranges from small to great depending on the particular characteristics of the tank system and the retardant type. Since it affects the pattern, aircraft and ground safety, drop height is a primary variable in these guides.

AIRCRAFT VELOCITY — The aircraft velocity with respect to the ground changes the retardant distribution as shown, but its effect on the coverage levels of interest is not usually as significant as might be supposed. Flying faster will generally reduce peak coverage values, increase pattern momentum, and increase low coverage lengths. All data in these guides are based on the mid-velocity of the specific aircraft.

AIRCRAFT MANEUVER — The effects of dive or toss modes of release are similar to velocity. Diving tends to foreshorten the pattern and increase coverage. The effect is similar to reducing velocity. Toss tends to elongate the pattern. The effect is similar to increasing aircraft velocity. Maneuver selection is more related to the ability to place the pattern accurately than it is to the coverage levels obtained. It is not considered a primary variable in these guides.

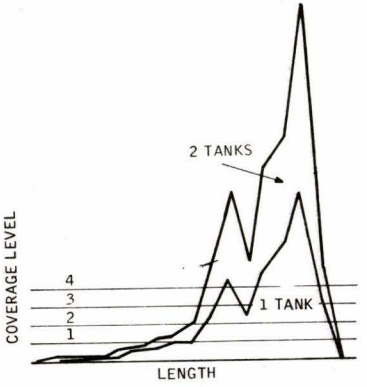
WIND — The effect of wind is to deflect the pattern and greatly increase the pattern's fringe area. It does not generally diminish pattern area or length significantly at the 1- through 4-gallon-per-hundred-square-foot coverage levels. Like drop height, wind will exert a greater influence on water-like retardants, than on gum-thickened products. The smaller drops are more susceptible to drift, deflection, and increased evaporation losses than the larger drops of gum-thickened retardants. Since the effect is more related to placement accuracy than coverage extent, all data in the guides is generated under a theoretical no-wind condition.



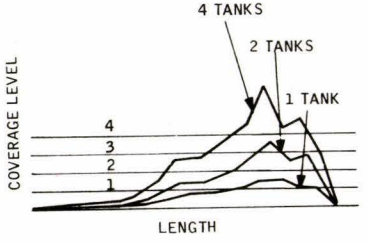
Number of Tanks Determines Aircraft Flexibility

Most aircraft carry at least two tanks, with some containing as many as eight. Considerable control can be exerted on the pattern by the judicious use of the tanking increments available and the time between tank releases.

- Dropping two tanks simultaneously (in salvo) doubles the flow rate and, consequently, the coverage level. It does not necessarily double the length or area at a useful coverage level.

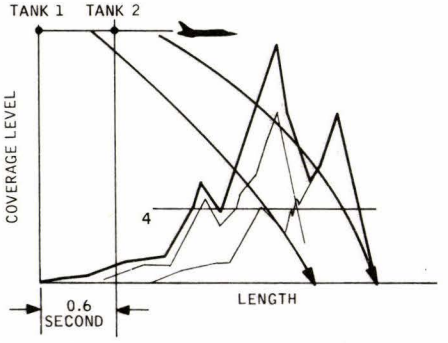


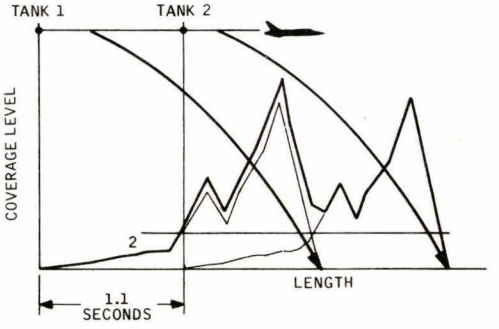
- For some tanking systems, multiple-tank salvos are useful to bring pattern coverage up to the appropriate values: To accommodate the effects of increased altitude or to increase flexibility.



Pattern Can Be Controlled by a Delayed Release Sequence

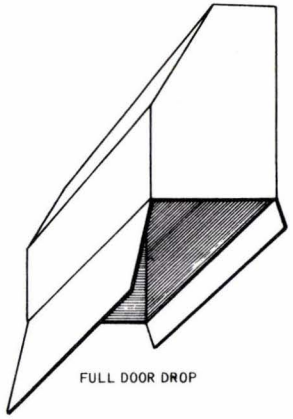
In most cases, the most efficient use of multiple tank drops occurs when individual tank releases are spaced along the aircraft flight path. The appropriate delay interval will vary with drop height, aircraft velocity, retardant type, and the desired coverage level. Few aircraft are equipped to regulate appropriate delays accurately. Nonetheless, delays of the right order can be approximated to maximize pattern length at the required coverage level.



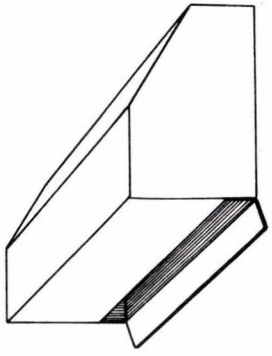


Door Options Can Be Used to Control Flow Rate

Some aircraft offer additionai control options by offering a choice of door areas used in the drop. Depending on the desired pattern level either the full door or a door representing some smaller fraction of the tank bottom can be selected.

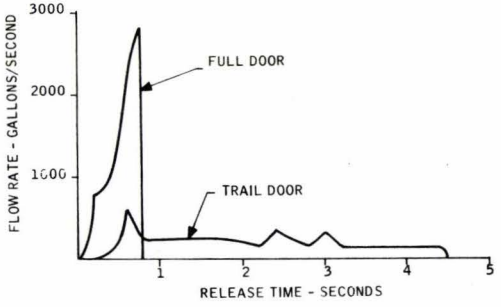


FULL DOOR DROP

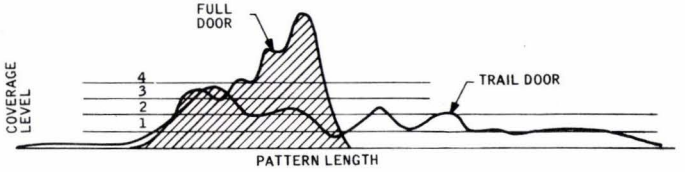


TRAIL DOOR DROP

Flow Rates Available From One Tank With Two Door Options . . . .



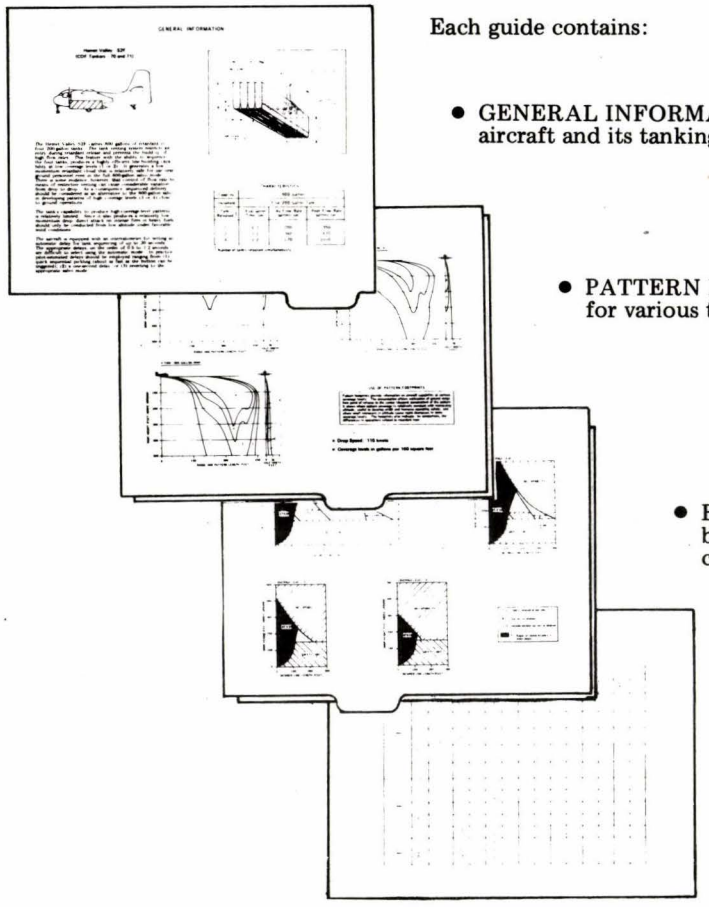
. . . . Yield Two Types Of Ground Pattern



Organization of User Guides

The User Guides are booklets that display data on specific aircraft, in forms useful to the tanker pilot, air attack and ground personnel in achieving the most efficient use of the aircraft.

Each guide contains:



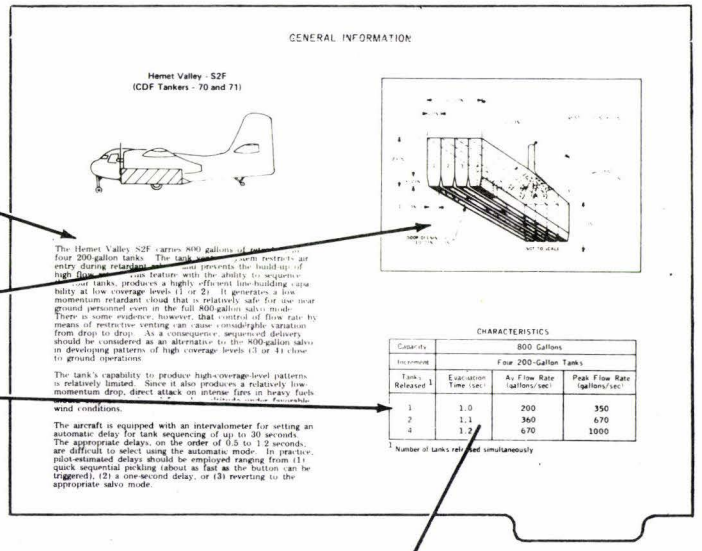
- GENERAL INFORMATION — A brief description of the aircraft and its tanking system
- PATTERN FOOTPRINTS — Plots of pattern coverage levels for various types of drops and retardants.
- BEST STRATEGY CHARTS — Enabling quick selection of the best number and sequence of tanks to be employed for specific coverage requirements and line length.
- DETAILED TABLES — Showing the line length and specific settings for delayed release to achieve maximum coverage at a large number of coverage levels and altitudes

The following pages discuss the use of this information.

Use of "General Information" Section

The general information section contains three elements:

- A description and assessment of the aircraft tanking system in terms of its limitations and capabilities. It is particularly useful in comparing the aircraft with others that might be used in the region, so that differences in the ways the tankers are employed are generally apparent.
- A schematic drawing of the tank showing the pattern control options available.
- A table of characteristics showing typical tank evacuation times, retardant capacities, and average and peak flow rates.


GENERAL INFORMATION

Hemet Valley - S2F
(CDF Tankers - 70 and 71)

CHARACTERISTICS

Capacity	800 Gallons		
Increment	Four 200-Gallon Tanks		
Tanks Released [1]	Evacuation Time (sec)	Av Flow Rate (gallons/sec)	Peak Flow Rate (gallons/sec)
1	1.0	200	350
2	1.1	360	670
4	1.2	670	1000

[1] Number of tanks released simultaneously

Using these data, it is possible to compare aircraft quickly. Performance similar to that of a familiar aircraft will generally occur under conditions where the average flow-rates are comparable. For example: A 1000-gallon tank with a 235-gallon-per-second flow-rate is known to produce patterns effective against fires in your region. A new tanker with four 200-gallon tanks becomes available that offers 200-, 400-, and 800-gallon-per-second flow-rate options. Comparable coverage levels (but considerably shorter patterns) will be obtained using the 200-gallon-per-second (single-tank) release under similar delivery conditions. Conversely, if an 800-gallon tank with 1000 gallons per second peak flow has been used effectively in close-support operations, an apparently comparable 750-gallon tank producing a 2000 gallons per second peak flow can be recognized as a potential hazard to ground personnel if flown at the same delivery altitude.

CHARACTERISTICS

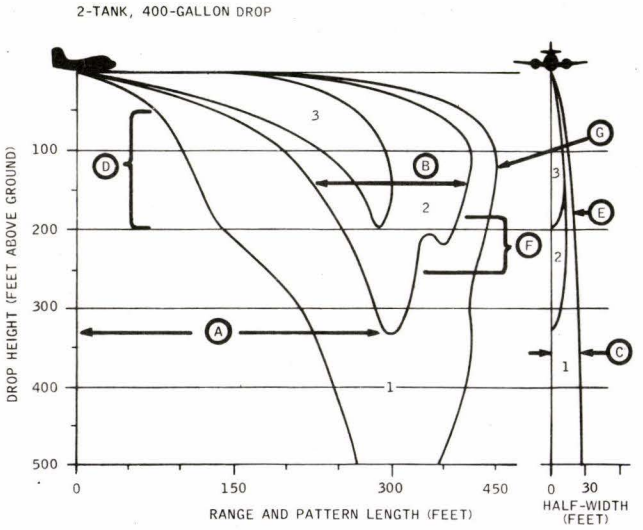
Capacity	800 Gallons		
Increment	Four 200-Gallon Tanks		
Tanks Released [1]	Evacuation Time (sec)	Av Flow Rate (gallons/sec)	Peak Flow Rate (gallons/sec)
1	1.0	200	350
2	1.1	360	670
4	1.2	670	1000

[1] Number of tanks released simultaneously

- Average Flow Rate: An indicator of coverage levels generated in the pattern — the lower the value, the lighter the pattern.
- Peak Flow Rate: An indicator of the pattern's momentum. Values much above 1000 gallons per second should be considered as potentially dangerous to ground personnel when released at low altitudes.

Pattern Footprints

Pattern footprints provide information on aircraft capability at various coverage levels over the altitude range. They are generated at the mid-aircraft velocity and show by inspection several important factors of the drop.



(A) Approximate ground range from point-of-release to the center of the pattern, the point of highest concentration. This is useful in estimating the appropriate point of release to place the pattern on spot fires.

(B) The approximate length of the pattern at a given coverage level at the selected drop height. This value can be used in association with observed response of the fire to the drop pattern, to check or refine the recommended coverage level values in specific fire situations.

(C) The effect of altitude on pattern width. Note in this case the maximum area coverage at 1 occurs around 190 feet where the width is greatest just prior to the reduction in length. (E)

(D) Non-critical drop heights. The pattern is relatively insensitive to uncontrolled variables within this range. Small changes of altitude do not cause the pattern to drop below the recommended coverage level. Contrasted to (F)

(F) A critical drop height, where the pattern line (at level 2) falls off rapidly, can become discontinuous, and is sensitive to variables such as wind or drop height.

(G) An indication of the drop height at which the retardant mass loses its forward velocity and falls vertically.

Example-Use of Pattern Footprint to Estimate Effective Coverage Level

A hypothetical 800-gallon drop (A) was made from the Hemet Valley-S2F using Fire-Trol 100 (B) at an estimated drop height of 200 feet. (C)

The lineboss estimated that the drop pattern was significantly effective over not more than 150 feet. (D)

From the footprint, the coverage level appropriate to the specific fire fuel situation can be estimated as shown at right. By comparing the estimated effective length with the coverage level profiles, we can estimate the minimum useful coverage at about 3. (E)

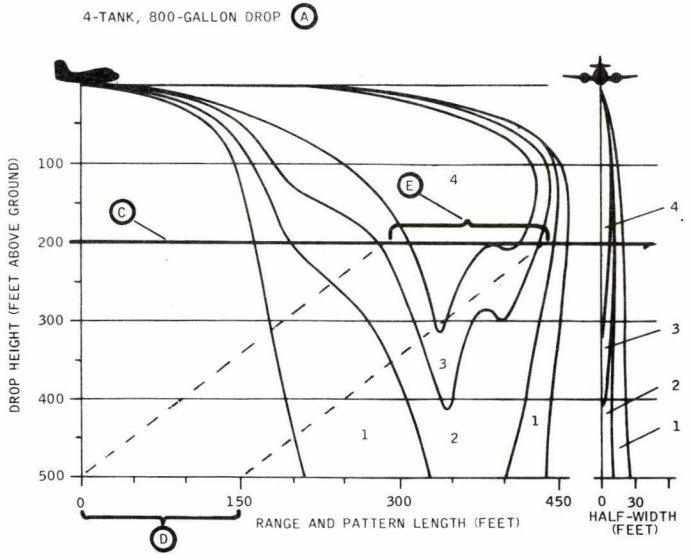
Subsequent evaluation showed the fire was absolutely extinguished for about 50 feet along the flight path.

From the Line Length/Opening Delay tables, the coverage level for extinction can be estimated by examining the estimated lengths at higher coverage associated with the drop. (F)

By this process, in association with intelligent experimentation, it is possible to utilize an aircraft with reasonably well-defined drop characteristics to gather important information on the effect of retardants on actual fires. For this reason, drop post-mortems and data collection are encouraged.

Pattern Coverage Characteristics - WATER-LIKE Retardants

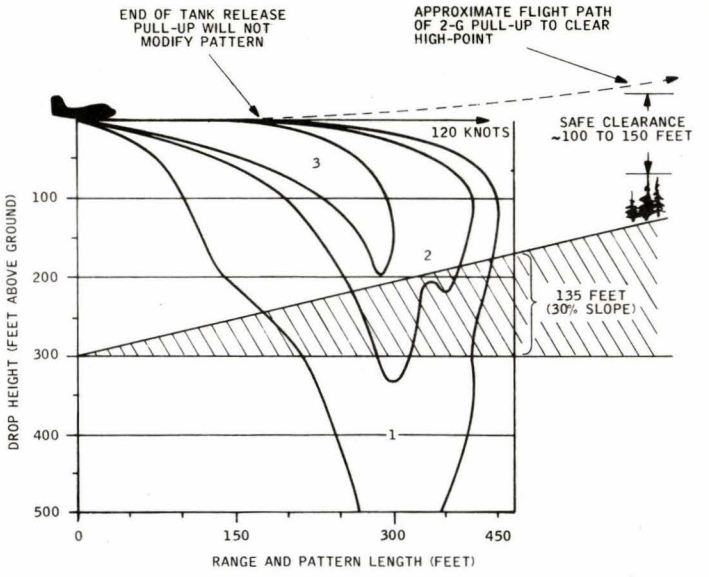
(B) [Fire-Trol 100, Fire-Trol 931 (LC) and Water]



NO. OF TANKS RELEASED AT A TIME	DROP HEIGHT (FT)	NO. OF PATTERNS	LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4			
			COVERAGE (GALLONS/100 FT^2)											
			0.5		1.0		2.0		3.0		4.0		6.0	
			MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
		2	505	1.3	245	0.0	70	0.2	--	--	--	--	--	--
(A)	150	1	325	0.0	295	0.0	270	0.0	220	0.0	145	(F) 0.0	30	0.0
4 TANKS (C)	200	1	320	0.0	290	0.0	250	0.0	160	0.0	105	0.0	5	0.0
	300	1	315	0.0	275	0.0	180	0.0	80	0.0	15	0.0	--	--
	400	1	290	0.0	265	0.0	120	0.0	15	0.0	--	--	--	--
	500	1	285	0.0	240	0.0	40	0.0	--	--	--	--	--	--

Up-Slope and Down-Slope Drops

The pattern footprints can also be employed to estimate the coverage achievable and approximate release points in terms of altitude and range for drops against severe slopes. In the example at right, a 30% grade is shown as a rise of 135 feet over the 450-foot span of the graph. A straight-edge moved across the footprint at the appropriate angle allows assessment of appropriate release strategy or the ground coverage levels developed. With some additional calculations, the ability of the aircraft to accomplish the drop and to escape safely can be examined under various terrain-clearance conditions.



Best-Strategy Charts

Best Strategy charts summarize the Line Length/Opening Delay tables to allow quick identification of the number of tanks and approximate delays between releases which will achieve the most efficient use of the retardant load for any combination of coverage level, line length, and drop height restrictions. A key to their usage accompanies the charts.

Several important points can be made from inspection of these charts.

First, the selection of a coverage level above what may be necessary can produce a large reduction in efficiency, particularly at low levels. It penalizes aircraft tanking systems with considerable flexibility, if they are asked to perform in a "give me as much as possible" way.

Second, it shows ground personnel and mission planners what can specifically be expected from the aircraft. It allows assessment of whether the use of a full load (drawing maximum line), higher coverages, or multiple drops are more efficient in a given fire attack situation.

Finally they indicate where ground safety or accuracy limits can be anticipated in direct-attack or close-support operations.

Use of Best-Strategy Charts

(A) Select the charts for the retardant type to be employed in the operations. This will be GUM-THICKENED (such as Phos-Chek) or WATER-LIKE (such as Fire-Trol 100).

(B) Select the chart for the appropriate coverage level for fuel and fire situations in the area of operations.

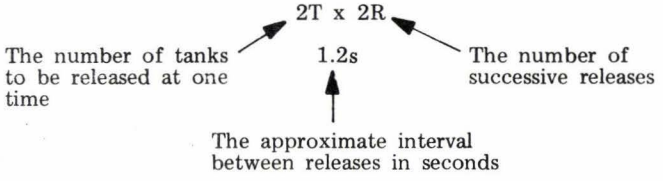
Coverage Level	Recommended For:	
	Fuel Model	Description
1	A	Grasses; tundra, and open desert shrub lands
2	C	Conifer timber with grass understory
	F	Brushfields with much green material
3	D	Shrublands under 6 feet in height (such as sagebrush)
	E	Hardwood litter after leaf drop
	H	Closed conifer timber with litter only
4	B	Hard chaparral and other high (6-foot) flammable shrubs
	G	Closed, old conifer timber with litter and dead, down limb wood.
	I	Conifer slash

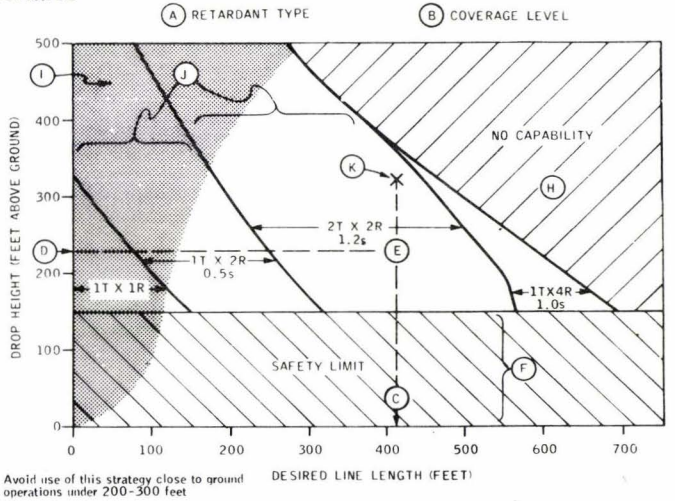
For creeping or smouldering fires reduction of one coverage level may be considered.

(C) Estimate the length of line required for a particular drop at the selected coverage level.

(D) Determine drop-height limits: (1) to assure aircraft safety in clearance of terrain features both before and after the planned release and (2) to protect ground personnel in close-support operations.

(E) Identify the region on the chart defined by the line-length, drop-height condition. This will identify the best release strategy to achieve the required coverage:


2T x 2R
1.2s
The number of tanks to be released at one time
The number of successive releases
The approximate interval between releases in seconds



(G) NOTE: Avoid use of this strategy close to ground operations under 200-300 feet

(F) SAFETY LIMIT -- Usually expressed as a fuel clearance distance; will normally be at 150 feet above ground or greater depending on terrain or fuel features

(G) NOTES -- Indicate recommended altitude limits for high-momentum drops potentially dangerous to ground personnel when used in close support or call out other recommendations or limitations for a particular strategy.

(H) LIMITS OF CAPABILITY -- The aircraft cannot produce, in a single pass, line-length greater than that defined by the limit curve.

(I) REGION OF LIMITED ACCURACY -- The ability to place a pattern of the specified coverage level on a spot fire is doubtful if operations must be conducted in this region.

(J) OPERATING REGIONS -- Most efficient use of the available retardant and pattern controls will occur for the strategy listed. For more precise intervalometer settings see the detailed tables.

(K) If the desired drop is well within the line capability of the release strategy, consider flying higher. This will result in a wider pattern and increased safety.

Maximum Line Length/Tank-Opening Delay Tables

The Maximum-Line-Length tables show, for a selected altitude, the appropriate delay between tank releases to achieve the maximum coverage over a range of potentially desirable coverage levels.

(A) The number of tanks released simultaneously is the basic building block of the pattern. Thus the value 2 indicates a two-tank salvo. The number of patterns (B) tells how many salvos are delivered. The column entries tell the maximum length of line that can be achieved with reasonable certainty at any coverage level as well as the correct interval setting (C) between salvo releases to achieve this value. These delays are far more precise than those presented in the best strategy charts.

Note that intermediate values can be estimated, if desired, by interpolation between points listed.

(A)		(B)	LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4			
			COVERAGE (GALLONS/100 FT^2)											
			0.5		1.0		2.0		3.0		4.0		6.0	
NO. OF TANKS RELEASED AT A TIME	DROP HEIGHT (FT)	NO. OF PATTERNS	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC) (C)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
	150	1	275	0.0	140	0.0	--	--	--	--	--	--	--	--
		2	565	1.5	330	1.0	145	0.1	35	0.0	--	--	--	--
		4	1145	1.5	710	1.0	395	0.7	230	0.0	145	0.2	35	0.0

Comparison of Retardant Capabilities

All data in the guidelines is presented for two different types of retardant compositions. The distinction is based on the type of thickening agent which causes considerable performance differences in the way the retardant breaks up and survives over the altitude range. The two types are identified as:

- Gum-thickened - including Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)
- Water-like - including Fire-Trol 100, Fire-Trol 931 (LC) and water

The categories refer to rheological properties that influence the breakup in the airstream, not to their effects in coating the fuels or controlling the fire. Indeed, the evidence suggests that their operations on the fuels are nearly equivalent.

The advantage of the gum-thickened retardant appears to reside in its tendency to break into larger droplets, providing less surface area to evaporation effects, and a higher drop momentum that resists wind deflection. This is shown by comparing the pattern footprints on the following two pages.

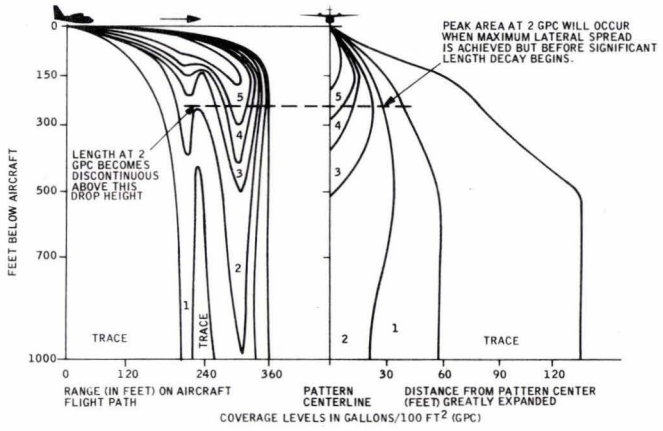
That the two types of retardant are equivalent in other respects is supported by the following evidence:

- Fuel Surface Coating: Although clay-thickened retardants produce relatively thicker coatings than gum-thickened retardants in dip tests (static conditions), they appear to produce thinner coatings when splashed against the fuel surface (dynamic conditions). Since both conditions contribute to actual fuel coating, the differences might well be offsetting. Observations in the field tend to support this contention in that it is difficult to tell the difference between retardant compositions by the fuels coverage in areas of similar concentration.

- Retardant Effects on the Fire: The active salts of commonly used retardants produce differing effects on certain fires. In terms of the effect on spread rates, which is critical to most air-delivery missions, the salt concentration is set to produce essentially equivalent effectiveness. Indeed the differences are sufficiently minor that a single value of Maximum Useful Concentration closely defines both commonly used retardant effects (reference: Rothermel, R.C., and Philpot C.W., "Reducing Fire Spread in Wildland Fuels," Northern Forest Fire Laboratory, Missoula, Mont. July 9, 1974).

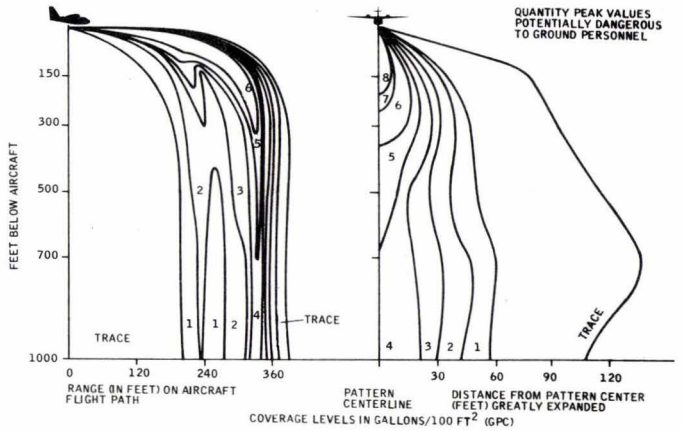
Altitude Effects on Water-Like Retardants

The accompanying graphs show the depth of altitude survival for various coverage levels in a single-tank drop of waterlike retardants. They provide an indication of the achievable length of line at any given coverage level. Note that the pattern width tends to increase as the retardant falls, until the processes of pattern decay (evaporation losses and over-spread) began to offset the advantages of increasing width. This process yields maximum area coverage at delivery altitudes that are often higher than the lowest safe delivery. In this case the maximum area above 2 gpc would be expected to occur at about 230 feet.



Altitude Effects on Gum-Thickened Retardants

Phos-Chek XA exhibits the altitude performance conditions shown in the accompanying graphs. The pattern retains its coherency over a far greater altitude range than for water-like retardants. This is caused by the formation of larger, more uniform drops that lose less due to evaporation and diffusion as the pattern spreads. In this example, the pattern width reaches a peak at around 250 feet which also corresponds to the maximum length value.



Notes on Pattern-Placement Accuracy

For a retardant pattern to be effective, we must place it where we want it on the ground. This implies that there is an aimpoint--some landmark or feature that can be recognized as a target. Some targets are precisely defined--such as the origin of smoke or flame of a spot fire or the reddened fuels of a prior line-drop that must be tied in. Others are not points of reference, but objectives--across the right flank of the fire. In this case some arbitrary aimpoint must be assumed as the reference for placing the drop. The position of the aimpoint is not the only uncertainty in achieving pattern placement. Others include:

- Systemic Uncertainties
  - Ground speed
  - Altitude
  - Aiming error
  - Pilot reaction time
  - True line of flight.
- Tank and Retardant Uncertainties
  - Trajectory variability
  - Ballistic errors
  - Wind
  - Equipment response time.

Values of these uncertainties, taken from known data or estimates, are tabulated in an error budget.

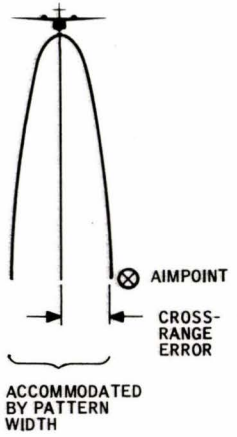
It is convenient to identify these uncertainties into two effects on placement accuracy:

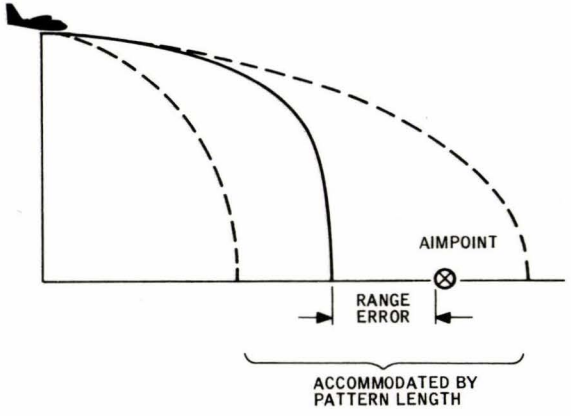
1. Cross-Range Errors - Related to the distance the pattern is left or right of the aimpoint.

2. Range Errors - Related to the time of release and aircraft position with respect to the aimpoint along the flight path. It is the distance the pattern is up or down-range from the aimpoint.

Range Errors are the largest source of accuracy problems identified in the error budget. They are also the most easily overcome; i.e., we can, within limits of the tanking system, generate longer patterns to accommodate range errors.

Cross-Range Errors are smaller than range errors, but we can do little to correct them by manipulation of tanking options. Although the width of the pattern generally increases with altitude, it does not increase as fast as the cross-range error.



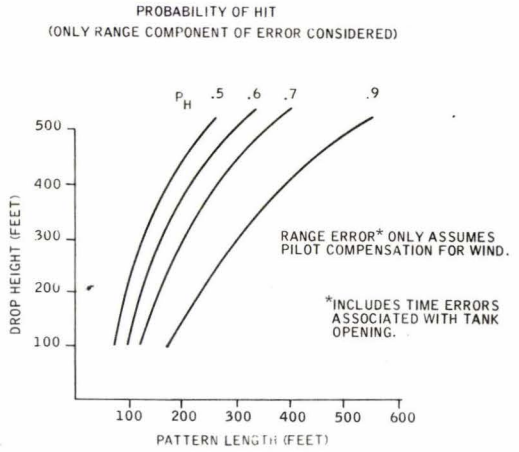


Generalized Probability of Hit

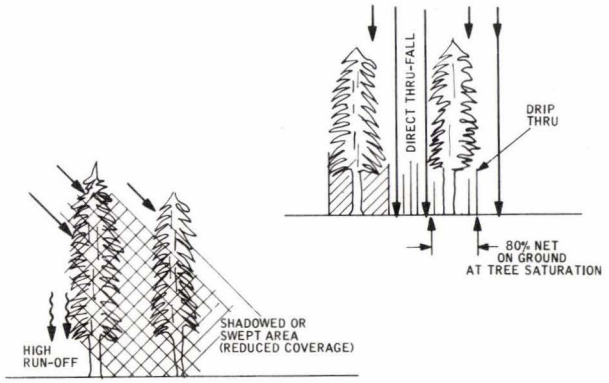
The accuracy of a given drop is both a function of the pilot's skill, unique characteristics of the aircraft, and the circumstances related to the drop. Therefore it is not practical to give fully prescriptive guidelines on accurate delivery. One feature of aircraft tanking systems, however, is their ability to accommodate range errors by increasing line length proportionately. This requires, of course, that the pilot commence his drop early and prolong the line beyond the estimated point of release to hit the intended aimpoint.

The figure shows the effect on probability of hit of generating longer line lengths under good (low-wind) delivery conditions. The value for a probability of hit of 60 percent is used on the Best Strategy charts to define the region of limited accuracy.

Three points are significant in controlling accuracy. First, it is best, where possible, to fly so that uncertainties are predominantly in range where increased length can overcome them--such as flying with the wind (or against it) versus on a cross-wind course. Second, it is more efficient to build the longest continuous line at adequate coverage level from a single aircraft pass than to attempt to connect patterns from separate deliveries. Third, since delivery accuracy is to a great extent dependent on pilot skill, the ability to place the pattern will be enhanced if similar retardant and drop missions are used repeatedly, allowing the pilot to develop experience in judging his drop trajectory.



Notes on Coverage of Ground Fuels



Two basic options for achieving adequate coverage of ground fuels beneath an overstory can be employed. They are:

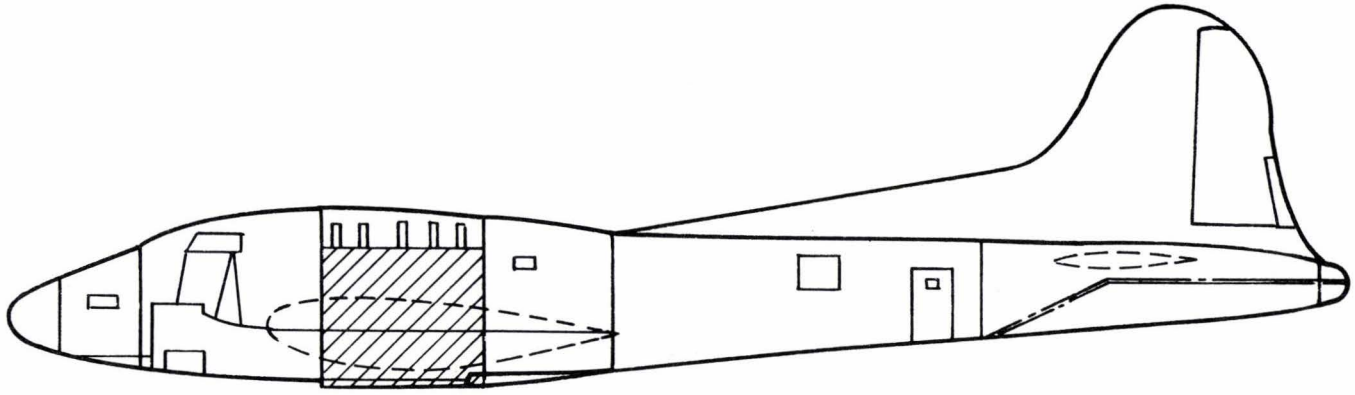
- Delivery in horizontal flight from relatively high altitudes which takes advantage of the vertical openness of most stands.
- Attempts to drive the retardant through the overstory by low-level or dive attack.

Use of the near-vertical fall of the retardant can be shown, in most cases, to yield the most uniform and consequently most efficient retardant distribution which maximizes direct thru-fall of open areas as opposed to the shielding of certain areas as the angle of entry is increased. Drip-thru as the vertical fuel discards excess retardant, prolongs the application time (on the order of 10 minutes) which can be a benefit.

ATTACHMENT 2

EXAMPLE USER GUIDE
(Aero Union B-17)

RETARDANT DROP USER GUIDE
for
AERO UNION B-17 AIRCRAFT
(TANKER 17)



Prepared by Honeywell Inc.
Government and Aeronautical Products Division
600 Second Street North
Hopkins, Minnesota 55343

15 February 1975

Contract 26-3332

Intermountain Forest and Range Experiment Station
USDA Forest Service
Ogden, Utah

This manual is published as a part of a program to improve fire control technology, specifically through the use of fire retardant chemicals and delivery systems whose chemical and/or design characteristics are tailored to fuel and fire situation needs. This program is being conducted at the Northern Forest Fire Laboratory. Information or questions regarding these studies should be directed to the:

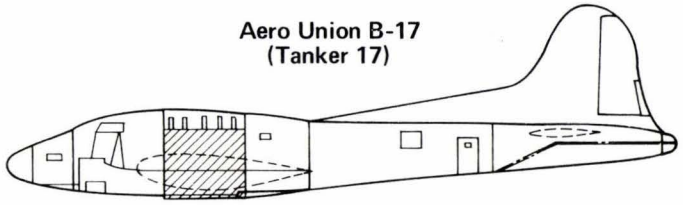
Northern Forest Fire Laboratory
Drawer G
Missoula, Montana 59801

Use of trade or firm names* is for vendor information only and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

* Phos-Chek is a registered trademark of the Monsanto Co.
Fire-Trol is a registered trademark of the Chemonics Industries
Gelgard is a registered trademark of the Dow Chemical Co.

GENERAL INFORMATION

Aero Union B-17
(Tanker 17)

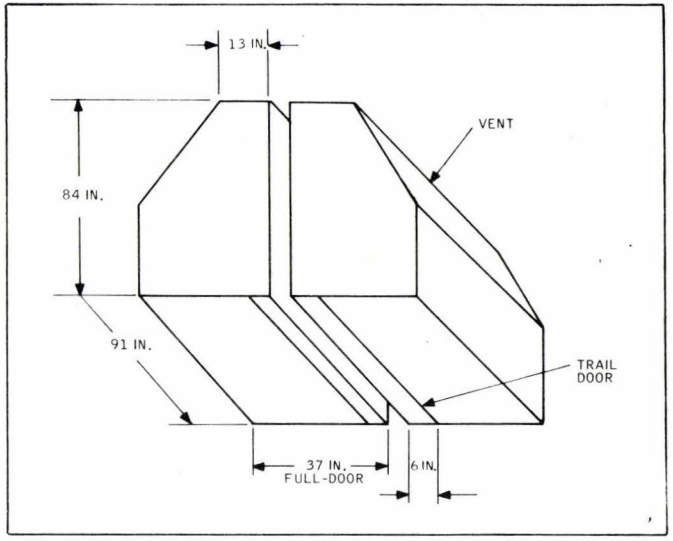


The Aero Union B-17 is equipped with two 1000-gallon tanks. Rapid door opening, large door area, and thoroughly adequate venting enable the aircraft to deliver exceptionally heavy retardant ground patterns. Trail doors allow pilot selection of a substantially lower flow-rate capable of producing considerable line at reduced coverage levels. It is thus capable of dealing with the most intense fires while preserving excellent capability for use against fires of lesser severity.

Full-door drops of 1000 or 2000 gallons produce a retardant mass with considerable momentum. It is wind resistant, accurate, and should penetrate intense fire plumes in quantities adequate for direct suppression. It has the capability to physically break vertical fuel structures (top or uproot trees, etc.) and represents a classic example of a tank system specifically designed for the direct suppression of intense spot fires by aircraft operations alone. Because of this capability, the full-door modes should be used with extreme care in any drops close to ground operations. The full-door two-tank drop should not be used and the full-door single-tank drop should be avoided at drop heights of less than about 300 feet.

Except for very high coverage levels (4 or better), best usage will normally be achieved by sequencing two single-tank drops or by employing the trail doors. The intervalometer on the aircraft is not readily accessible to the pilot, but the appropriate delay of 1 to 1½ seconds can be reasonably estimated by the pilot, and tank performance is not particularly sensitive to estimate errors in this range.

For line building at lower coverage levels (1 or 2), the trail doors should be employed, with a delay between tanks of 1 to 4 seconds. The 4-second delay should provide the most line at a coverage level of 1. Estimation errors on the short side reduce line length with a slight increase in coverage level. Errors above 4 seconds can produce discontinuities in the line.



CHARACTERISTICS

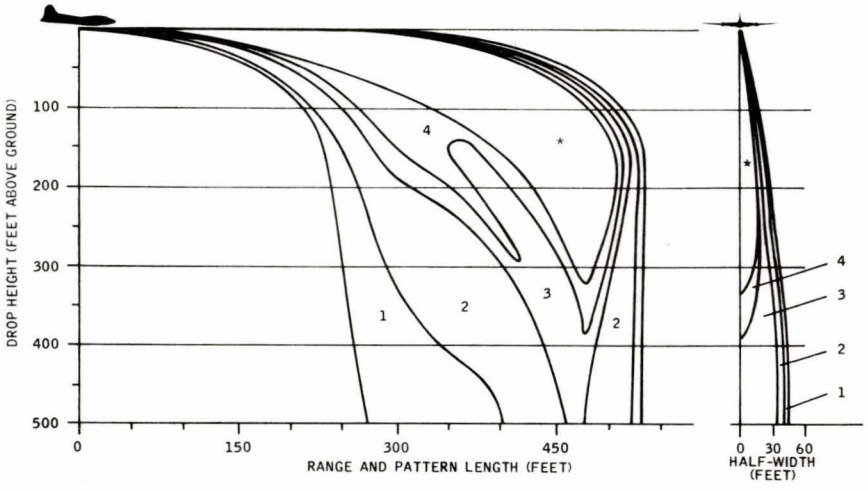
Capacity	2000 Gallons		
Increment	Two 1000-Gallon Tanks Salvo or Trail		
Tanks Released [1]	Evacuation Time (sec)	Av. Flow Rate (gallons/sec)	Peak Flow Rate (gallons/sec)
Full Door			
1	0.68	1470	2700
2	0.68	2940	5400
Trail Door			
1	4.26	235	315
2	4.26	470	630

[1] Number of tanks released simultaneously

Pattern Coverage Characteristics - WATER-LIKE Retardants

[Fire-Trol 100, Fire-Trol 931 (LC) and Water]

1-TANK, 1000-GALLON DROP

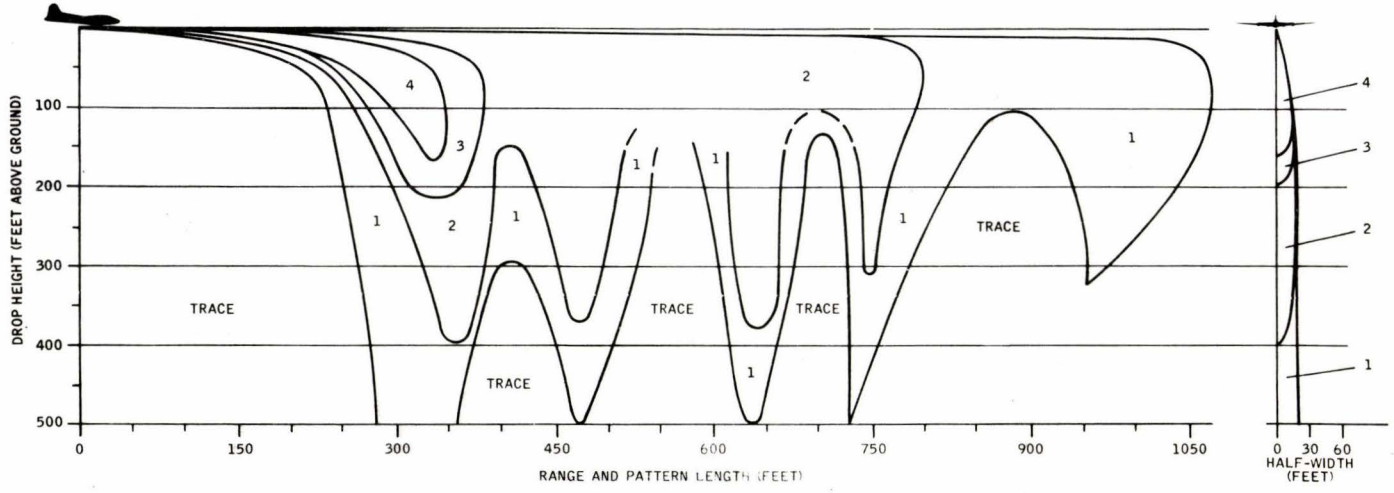


* Indicates coverage levels considerably above 5 gal/100 ft^2

Coverage Level	Recommended For:	
	Fuel Model	Description
1	A	Grasses; tundra, and open desert shrub lands
2	C	Conifer timber with grass understory
	F	Brushfields with much green material
3	D	Shrublands under 6 feet in height (such as sagebrush)
	E	Hardwood litter after leaf drop
	H	Closed conifer timber with litter only
4	B	Hard chaparral and other high (6-foot) flammable shrubs
	G	Closed, old conifer timber with litter and dead, down limb wood.
	I	Conifer slash

For creeping or smouldering fires reduction of one coverage level may be considered.

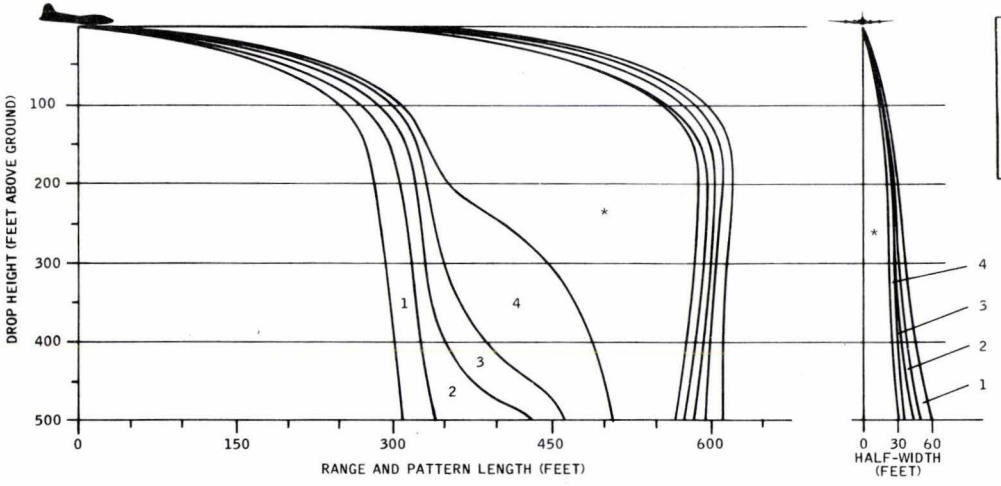
1-TANK, TRAIL-DOOR DROP



Pattern Coverage Characteristics - WATER-LIKE Retardants

[Fire-Trol 100, Fire-Trol 931 (LC) and Water]

2-TANK, 2000-GALLON DROP



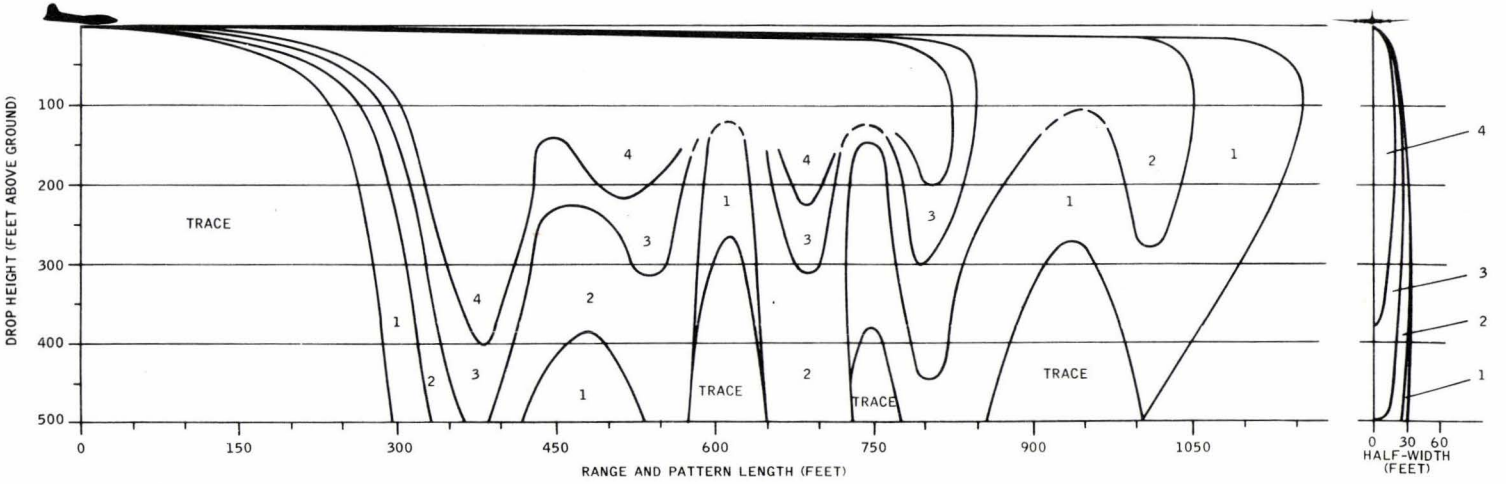
* Indicates coverage levels considerably above 5 gal/100 ft^2

USE OF PATTERN FOOTPRINTS

Pattern footprints provide information on aircraft capability at various coverage levels. The presentation allows estimation of ground range from point of release to the center (deepest penetration) of the pattern. It shows where pattern coverage is relatively constant with increasing altitude, useful to develop width and increase operating safety, and where small increases in altitude cause rapid decreases in some coverage levels. The footprints also indicate, by comparison, the differences in operations related to retardant type.

- Drop Speed: 120 knots
- Coverage levels in gallons per 100 square feet

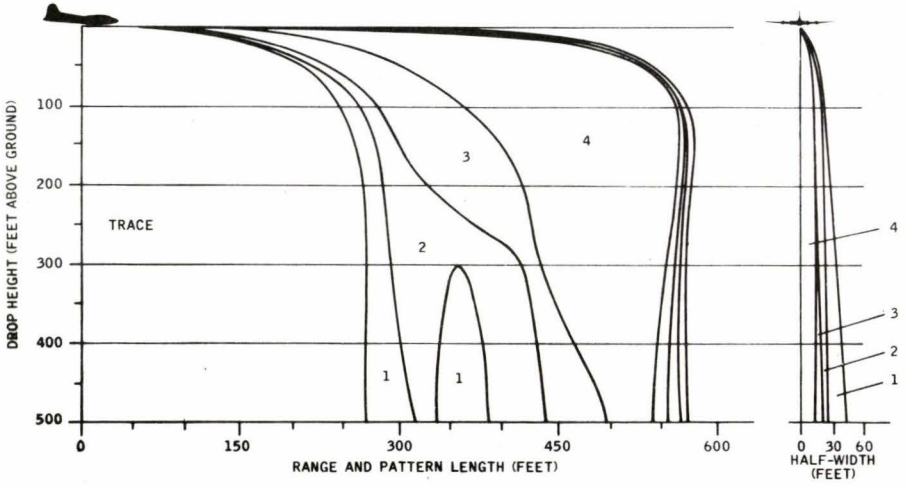
2-TANK, TRAIL-DOOR DROP



Pattern Coverage Characteristics - GUM-THICKENED Retardants

[Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)]

1-TANK, 1000-GALLON DROP



Coverage Level	Recommended For:	
	Fuel Model	Description
1	A	Grasses; tundra, and open desert shrub lands
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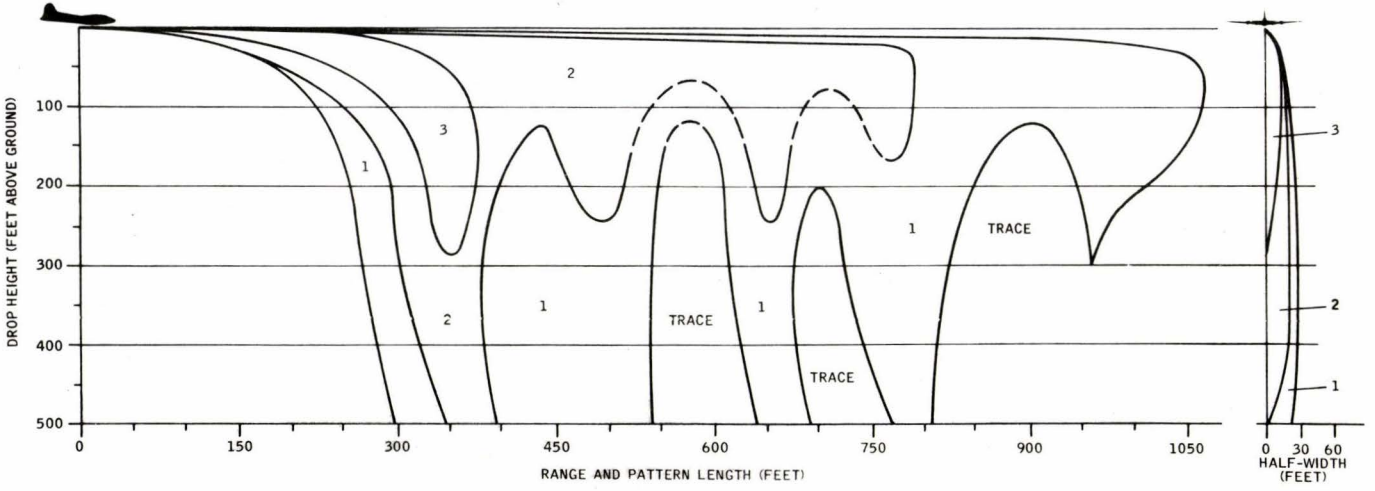
3	D	Shrublands under 6 feet in height (such as sagebrush)
	E	Hardwood litter after leaf drop
	H	Closed conifer timber with litter only
4	B	Hard chaparral and other high (6-foot) flammable shrubs
	G	Closed, old conifer timber with litter and dead, down limb wood.
	I	Conifer slash

For creeping or smouldering fires reduction of one coverage level may be considered.

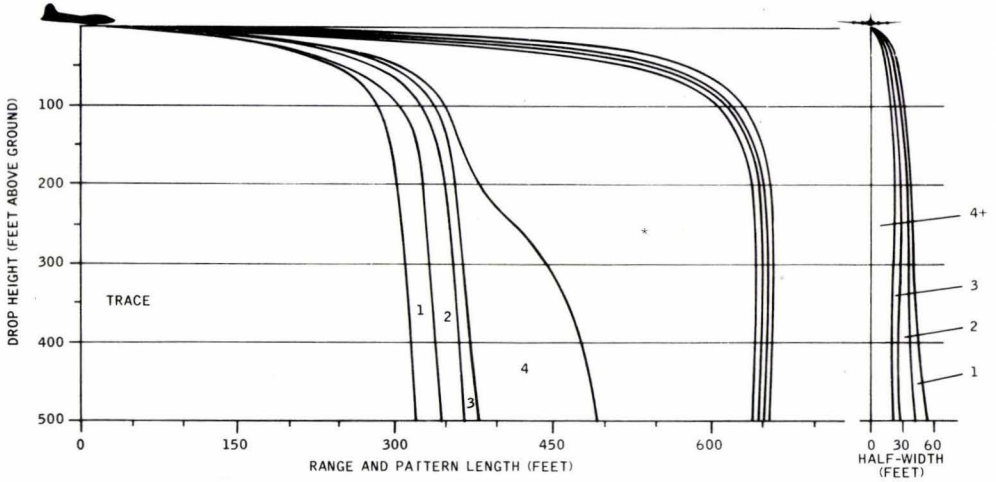
1-TANK, TRAIL-DOOR DROP



Pattern Coverage Characteristics - GUM-THICKENED Retardants

[Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)]

2-TANKS, 2000-GALLON DROP



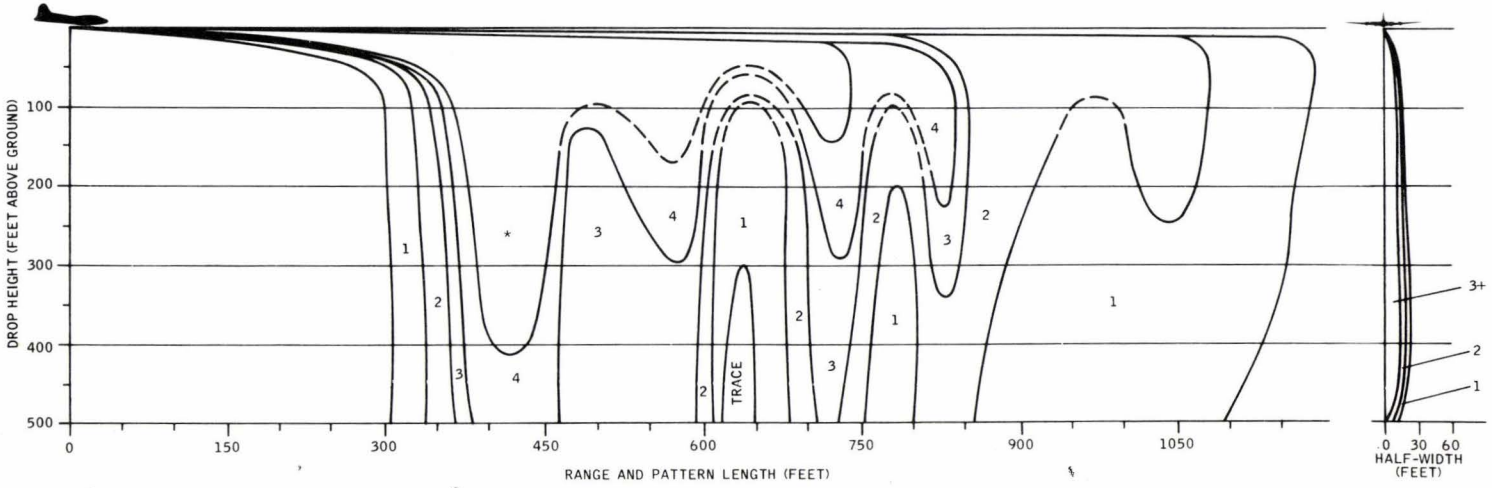
*Indicates coverage levels considerably above 5 gal/100 ft^2

USE OF PATTERN FOOTPRINTS

Pattern footprints provide information on aircraft capability at various coverage levels. The presentation allows estimation of ground range from point of release to the center (deepest penetration) of the pattern. It shows where pattern coverage is relatively constant with increasing altitude, useful to develop width and increase operating safety, and where small increases in altitude cause rapid decreases in some coverage levels. The footprints also indicate, by comparison, the differences in operations related to retardant type.

- Drop Speed: 120 knots
- Coverage levels in gallons per 100 square feet

2-TANK, TRAIL-DOOR DROP



* Indicates coverage levels considerably above 5 gal/100 ft^2

USE OF THE BEST-STRATEGY CHARTS

(A) Select the charts for the retardant type to be employed in the operations. This will be GUM-THICKENED (such as Phos-Chek) or WATER-LIKE (such as **Fire-Trol** 100).

(B) Select the chart for the appropriate coverage level for fuel and fire situations in the area of operations.

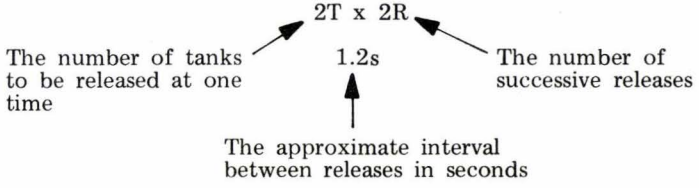
Coverage Level	Recommended For:	
	Fuel Model	Description
1	A	Grasses; tundra, and open desert shrub lands
2	C	Conifer timber with grass understory
	F	Brushfields with much green material
3	D	Shrublands under 6 feet in height (such as sagebrush)
	E	Hardwood litter after leaf drop
	H	Closed conifer timber with litter only
4	B	Hard chaparral and other high (6-foot) flammable shrubs
	G	Closed, old conifer timber with litter and dead, down limb wood.
	I	Conifer slash

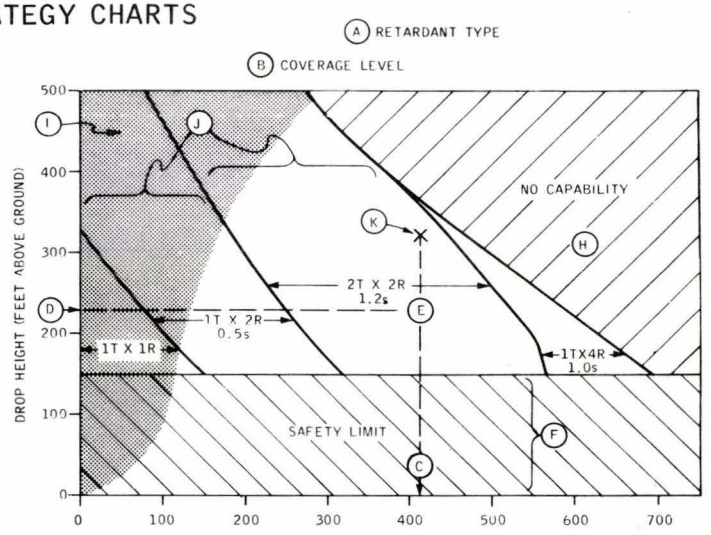
For creeping or smouldering fires reduction of one coverage level may be considered.

(C) Estimate the length of line required for a particular drop at the selected coverage level.

(D) Determine drop-height limits: (1) to assure aircraft safety in clearance of terrain features both before and after the planned release and (2) to protect ground personnel in close-support operations.

(E) Identify the region on the chart defined by the line-length, drop-height condition. This will identify the best release strategy to achieve the required coverage:


2T x 2R
1.2s
The number of tanks to be released at one time
The number of successive releases
The approximate interval between releases in seconds



(G) NOTE: Avoid use of this strategy close to ground operations under 200-300 feet

(F) SAFETY LIMIT -- Usually expressed as a fuel clearance distance; will normally be at 150 feet above ground or greater depending on terrain or fuel features

(G) NOTES -- Indicate recommended altitude limits for high-momentum drops potentially dangerous to ground personnel when used in close support or call out other recommendations or limitations for a particular strategy.

(H) LIMITS OF CAPABILITY -- The aircraft cannot produce, in a single pass, line-length greater than that defined by the limit curve.

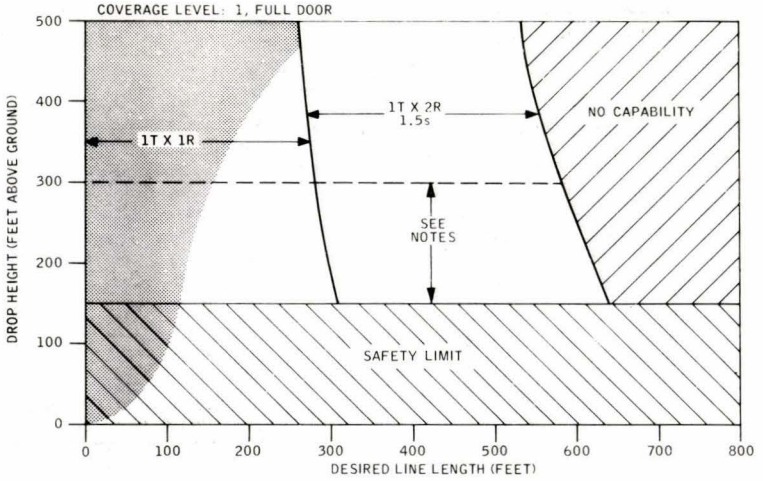
(I) REGION OF LIMITED ACCURACY -- The ability to place a pattern of the specified coverage level on a spot fire is doubtful if operations must be conducted in this region.

(J) OPERATING REGIONS -- Most efficient use of the available retardant and pattern controls will occur for the strategy listed. For more precise intervalometer settings see the detailed tables.

(K) If the desired drop is well within the line capability of the release strategy, consider flying higher. This will result in a wider pattern and increased safety.

Best Release Strategy - WATER-LIKE Retardants

[Fire-Trol 100, Fire-Trol 931 (LC) and Water]



NOTES: Use for direct attack only

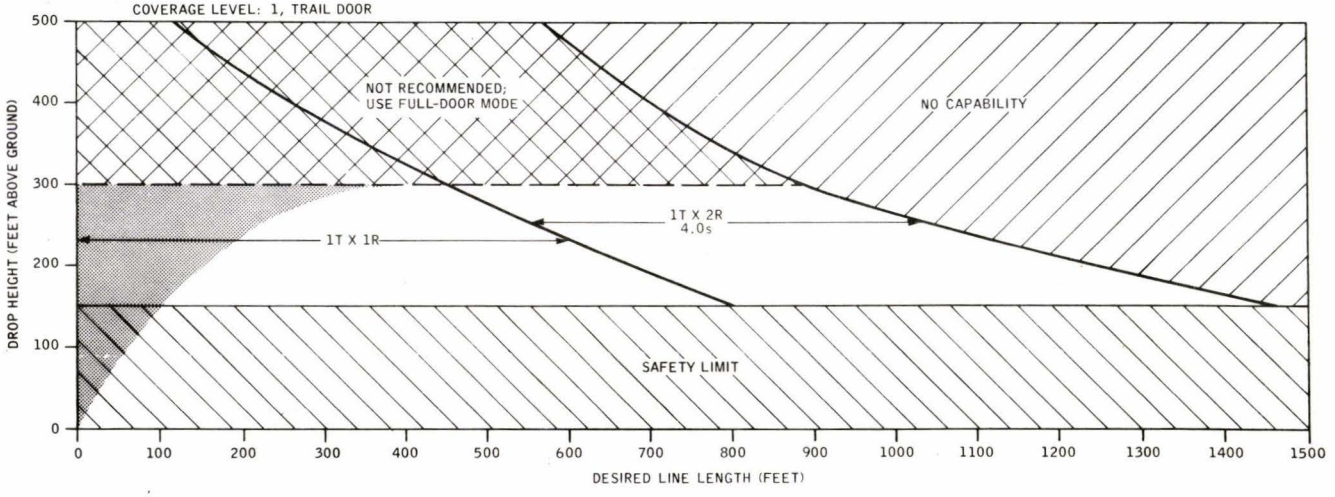
Use trail door in operations close to ground personnel.

T = Tank(s) released at one time

R = Successive releases

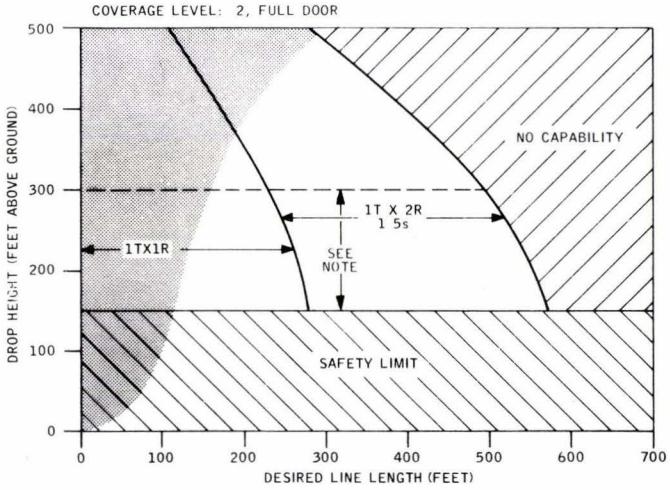
s = seconds between successive releases

= Region of limited accuracy in direct attack



Best Release Strategy - WATER-LIKE Retardants

[Fire-Trol 100, Fire-Trol 931 (LC) and Water]



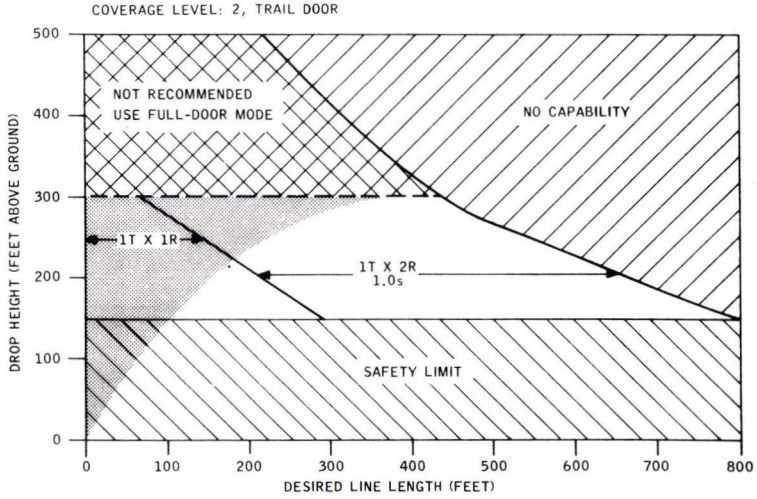
NOTE: Use trail-door mode for drops close to ground operations

T = Tank(s) released at one time

R = Successive releases

s = seconds between successive releases

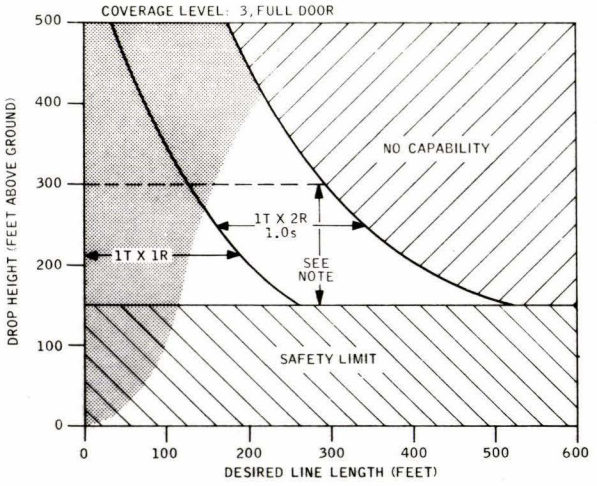
= Region of limited accuracy in direct attack



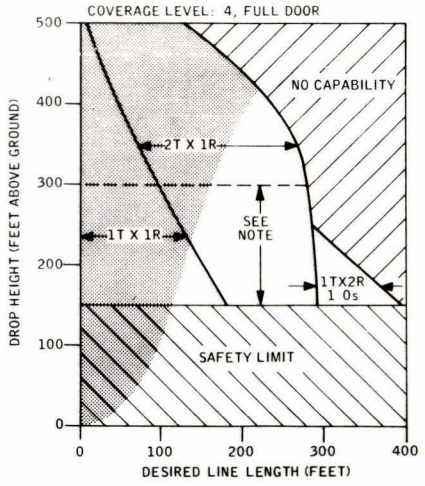
NOTE: Use only when drop must be made close to ground operations

Best Release Strategy - WATER-LIKE Retardants

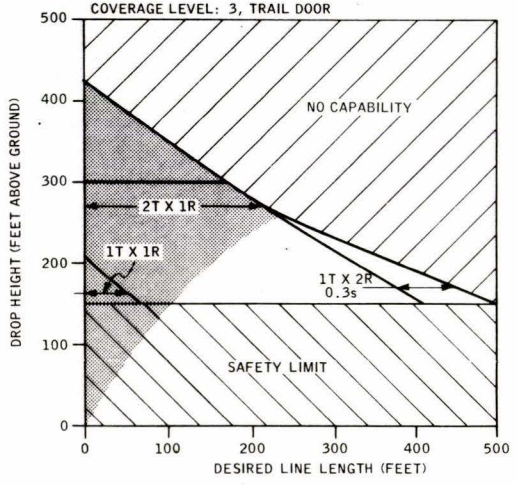
[Fire-Trol 100, Fire-Trol 931 (LC) and Water]



NOTE: Use trail-door mode if close to ground operations



NOTE: Use trail-door mode if close to ground operations



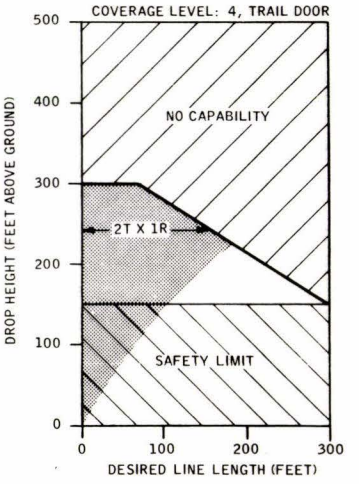
NOTE: Use only when drops are close to ground operations

T = Tank(s) released at one time

R = Successive releases

s = seconds between successive releases

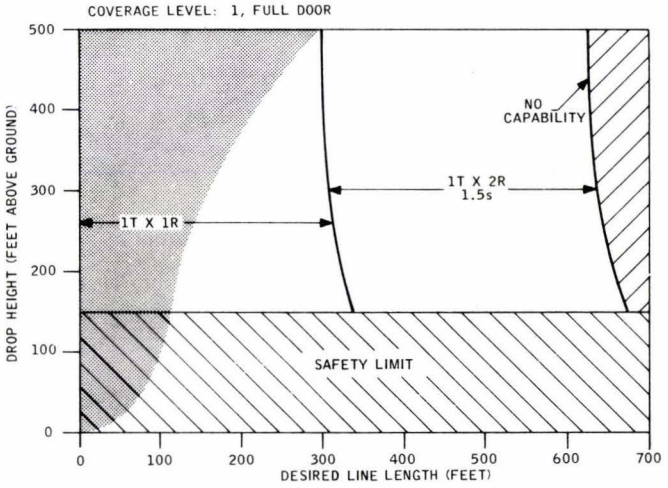
= Region of limited accuracy in direct attack



NOTE: Use only when drops are close to ground operations

Best Release Strategy - GUM-THICKENED Retardants

[Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)]



T = Tank(s) released at one time

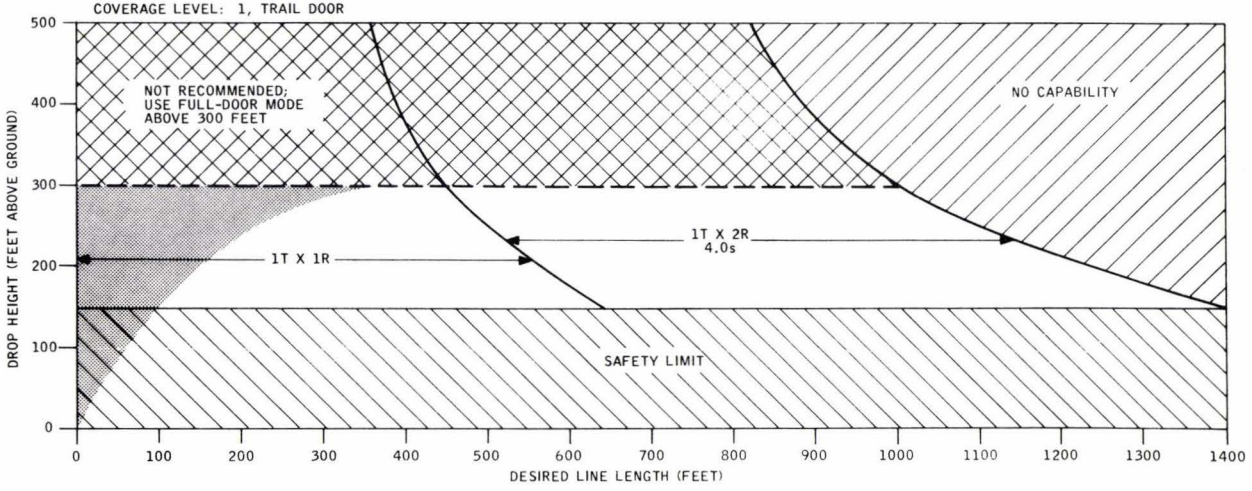
R = Successive releases

s = seconds between successive releases

= Region of limited accuracy in direct attack

NOTES: Use for direct attack only; otherwise use trail-door mode

Use trail-door mode in operations close to ground personnel



Best Release Strategy - GUM-THICKENED Retardants

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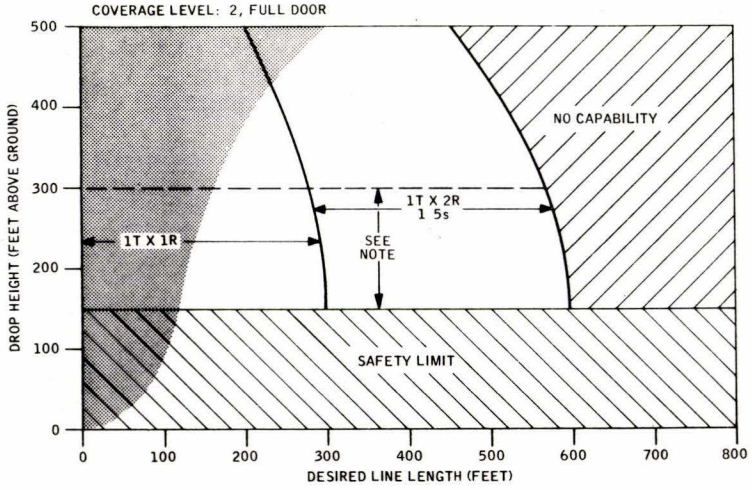

NOTE: Use trail-door mode for drops close to ground operations

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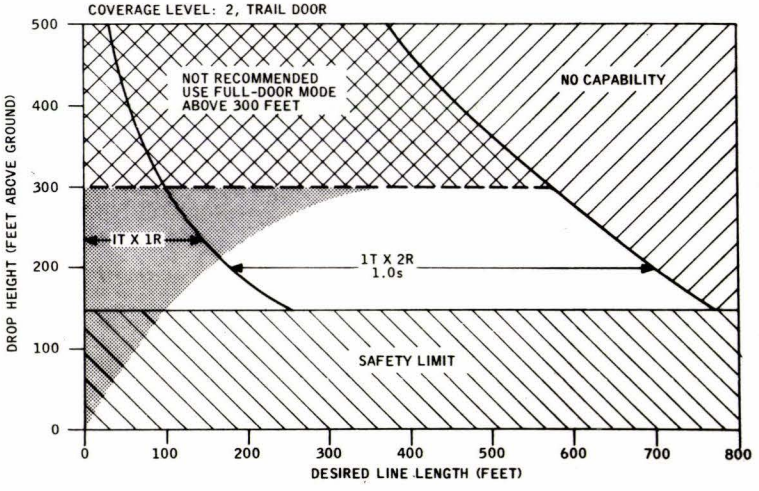
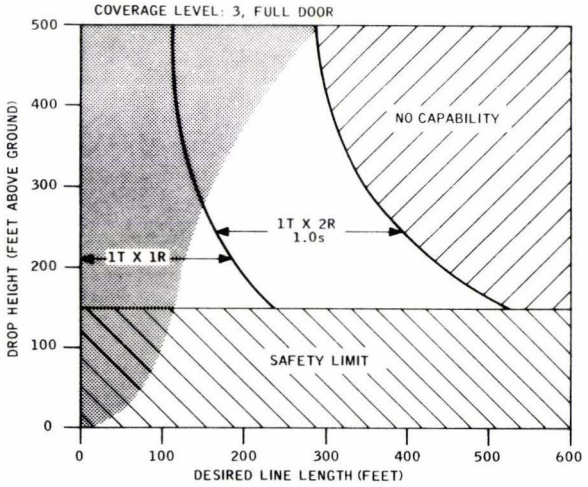
= Region of limited accuracy in direct attack



NOTE: Use only when drop must be made close to ground operations

Best Release Strategy - GUM-THICKENED Retardants

[Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)]



NOTE: Avoid use close to ground operations under 200-300 feet

T = Tank(s) released at one time

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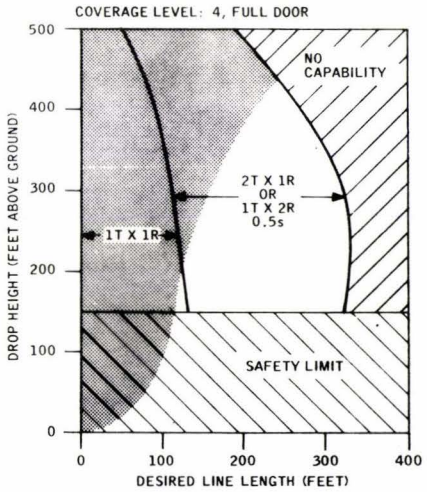

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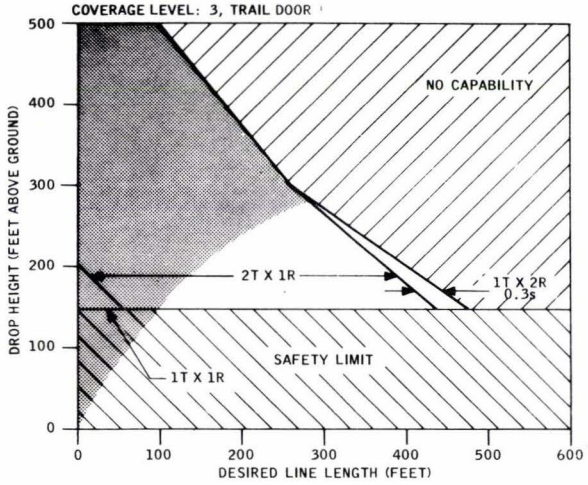
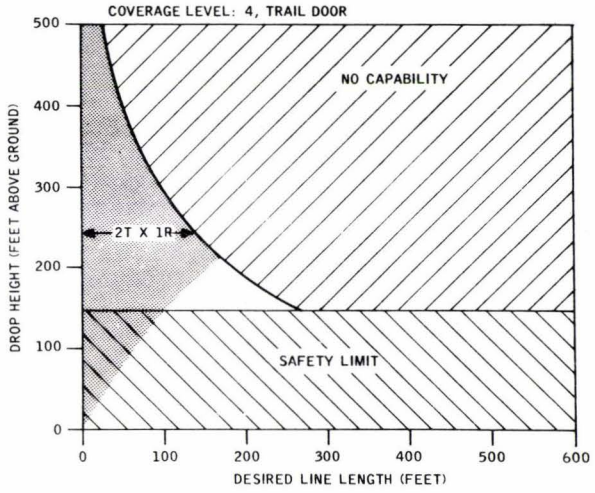


NOTE: Use only when drops are close to ground operations



NOTE: Use only when drops are close to ground operations

Maximum Line Lengths/Tank-Opening Delays - WATER-LIKE Retardants

[Fire-Trol 100, Fire-Trol 931 (LC) and Water]

			LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4							
			COVERAGE (GALLONS/100 FT^2)															
			0.5		1.0		2.0		3.0		4.0		6.0		8.0		10.0	
NO. OF TANKS RELEASED AT A TIME	DROP HEIGHT (FT)	NO. OF PATTERNS	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
FULL DOOR																		
1 TANK	150	1	345	0.0	310	0.0	280	0.0	255	0.0	175	0.0	105	0.0	40	00	--	--
		2	700	1.8	645	1.7	580	1.5	535	1.4	395	1.3	265	0.7	195	0.4	135	0.3
	300	1	325	0.0	285	0.0	225	0.0	120	0.0	95	0.0	--	--	--	--	--	--
		2	665	1.7	585	1.5	490	1.3	290	0.7	240	0.1	130	0.3	95	0.0	30	0.0
	500	1	290	0.0	255	0.0	110	0.0	30	0.0	--	--	--	--	--	--	--	--
		2	610	1.6	535	1.4	270	0.6	180	0.4	110	0.0	30	0.0	--	--	--	--
2 TANKS	150	1	410	0.0	375	0.0	340	0.0	315	0.0	290	0.0	260	0.0	155	0.0	120	0.0
	300	1	385	0.0	355	0.0	315	0.0	295	0.0	280	0.0	165	0.0	130	0.0	100	0.0
	500	1	355	0.0	300	0.0	260	0.0	140	0.0	115	0.0	35	0.0	--	--	--	--
TRAIL DOOR																		
1 TANK	150	1	890	0.0	695	0.0	295	0.0	75	0.0	15	0.0	--	--	--	--	--	--
		2	1630	4.7	1465	4.4	805	1.2	510	0.3	305	0.1	75	0.0	15	0.0	--	--
	300	1	800	0.0	390	0.0	65	0.0	--	--	--	--	--	--	--	--	--	--
		2	1645	4.5	875	3.0	425	0.3	140	0.0	65	0.0	--	--	--	--	--	--
	500	1	455	0.0	85	0.0	--	--	--	--	--	--	--	--	--	--	--	--
		2	1005	3.2	565	0.4	115	0.4	50	0.0	--	--	--	--	--	--	--	--
2 TANKS	150	1	940	0.0	890	0.0	660	0.0	425	0.0	310	0.0	75	0.0	20	0.0	--	--
	300	1	900	0.0	770	0.0	405	0.0	170	0.0	60	0.0	--	--	--	--	--	--
	500	1	850	0.0	445	0.0	85	0.0	10	0.0	--	--	--	--	--	--	--	--

Maximum Line Lengths/Tank-Opening Delays - GUM-THICKENED Retardants

[Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)]

NO. OF TANKS RELEASED AT A TIME	DROP HEIGHT (FT)	NO. OF PATTERNS	LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4							
			COVERAGE (GALLONS/100 FT^2)															
			0.5		1.0		2.0		3.0		4.0		6.0		8.0		10.0	
			MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
FULL DOOR																		
1 TANK	150	1	360	0.0	335	0.0	290	0.0	240	0.0	135	0.0	85	0.0	10	0.0	--	--
		2	725	1.4	675	1.7	600	1.6	520	1.4	340	0.9	260	0.1	160	0.3	115	0.0
	300	1	350	0.0	310	0.0	270	0.0	135	0.0	105	0.0	10	0.0	--	--	--	--
		2	705	1.8	630	1.6	570	1.5	335	0.9	270	0.0	155	0.2	105	0.0	55	0.0
	500	1	340	0.0	300	0.0	200	0.0	115	0.0	50	0.0	--	--	--	--	--	--
		2	690	1.8	620	1.6	445	1.4	280	0.6	230	0.4	115	0.0	55	0.2	--	--
2 TANKS	150	1	410	0.0	380	0.0	355	0.0	335	0.0	325	0.0	295	0.0	180	0.0	155	0.0
	300	1	395	0.0	375	0.0	350	0.0	330	0.0	315	0.0	200	0.0	170	0.0	120	0.0
	500	1	355	0.0	335	0.0	300	0.0	275	0.0	190	0.0	115	0.0	60	0.0	--	--
TRAIL DOOR																		
1 TANK	150	1	890	0.0	645	0.0	245	0.0	60	0.0	--	--	--	--	--	--	--	--
		2	1810	4.6	1395	4.4	775	1.1	465	0.3	245	0.0	60	0.0	--	--	--	--
	300	1	665	0.0	440	0.0	85	0.0	--	--	--	--	--	--	--	--	--	--
		2	1765	4.5	995	3.2	575	0.9	255	0.0	85	0.0	--	--	--	--	--	--
	500	1	735	0.0	360	0.0	40	0.0	--	--	--	--	--	--	--	--	--	--
		2	1540	4.4	825	1.9	360	0.0	105	0.4	40	0.0	--	--	--	--	--	--
2 TANKS	150	1	920	0.0	880	0.0	620	0.0	420	0.0	260	0.0	70	0.0	--	--	--	--
	300	1	910	0.0	835	0.0	450	0.0	255	0.0	85	0.0	--	--	--	--	--	--
	500	1	890	0.0	690	0.0	375	0.0	100	0.0	40	0.0	--	--	--	--	--	--